ANNEX F

Fish Passage and Fisheries Ecology

TECHNICAL REVIEW REPORT

on

Prior Consultation for the Proposed Luang Prabang Hydropower Project

Prepared by:

Mekong River Commission Secretariat

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CONTENTS

1. SCOPE OF REPORT

This report provides comments from the Fisheries and Environment Expert Group (FEEG) on aspects related to Fish Passage and Fisheries Ecology (subsequently called “fisheries issues”) based on a review of the EIA reports of the Luang Prabang Hydropower Project (LPHPP). The review is based on data and statements submitted under the PNPCA by the LNMC, as well as other information about the area. It also utilises the Preliminary Design Guidance (PDG 2009) cross-check forms Fish Ecology and Fish Passage (Annex 2) and checks the relevance of the updated Draft Preliminary Design Guidance (PDG 2019). In particular, the review tests the extent to which the advice on mitigation and management measures in the PDG 2009 for mainstream dams has been taken up.

The objectives of this report are

- To provide commentary about key issues to be addressed as part of the MRC’s Prior Consultation assessment of fisheries issues related to LPHPP, and
- To propose areas that may need further detailed discussion and support information.

The review attempts to provide assessment of potential transboundary impacts, risks and consequences of the proposed LPHPP on fisheries, particularly migratory species that migrate through the upper zone of the Mekong mainstream around Luang Prabang to complete their life cycles.

Whilst one of the main concerns of the Prior Consultation process is the transboundary impacts, the impacts on fisheries can only be assessed from an understanding of the scale and extent of the more localised impacts within the Luang Prabang area, before the river passes downstream towards Vientiane. Moreover, through Article 3 of the 1995 Mekong Agreement, the Member Countries have agreed to ‘maintain the ecological balance of the ‘Basin’, and through Article 7 to ‘make every effort to avoid, minimize and mitigate harmful effects that might occur to the environment, especially the water quantity and quality, the aquatic (ecosystem) conditions, and ecological balance of the river system’. This review consequently also assesses the extent to which these commitments are met.

It should be noted that some commentary is duplicated from the Pak Beng HPP TRR given the similarity in information provided and the regional context of much of the relevant background information available about the upper reaches of the Mekong in Lao PDR.

2. OVERVIEW OF LPHPP EIA DOCUMENTATION

The documents submitted as part of the PNPCA consultation process were reviewed in the context of understanding the potential impacts of the LPHPP on fish and fisheries in the region, together with evaluation of the proposed mitigation measures. The main documents formally submitted in relation to fish and fisheries were:

- Vol 1 - Executive Summary,
- Vol 2 - Main Feasibility Report,
- Vol 4-1 - ESIA,
- Vol 4-3 - EMMP,
- Vol 4.6 - Executive Summary of ESIA ,CIA-TBIA
- Vol 5 - TBIA & CIA
- Vol 6 Annex 6.6 - ESIA.

These documents contain primary fish ecological data, information about fish passage design and other potential mitigation measures as well as the cumulative and transboundary impacts of hydropower dams in the upper Lao cascade. Additional information on the methodologies for data collection for the prior assessment, during the construction phase and post construction period are provided. The information provided was supplemented by additional information and data contained in various MRC documents (see Annex 1 for baseline reference material).

The following additional document was provided in March 2020 at the end of the consultation period:

- LPHPP Backwater calculation report: velocities,
- LPHPP Baseline fisheries monitoring: from 1st field investigation report to 4th field investigation report,
- Appendix D: supporting information on aquatic ecology and fisheries
- Initial observations on Xayaburi HPP fish pass monitoring.

3. FISH ECOLOGY AND FISHERIES

Considerable information has now been accumulated about the fisheries of the Lower Mekong Basin, primarily by the MRC, line agencies within each riparian country, research institutions (national, regional and international), WorldFish and NGOs. This information has been compiled in numerous reports, but perhaps the most recent and comprehensive are the MRC State of the Basin Report (MRC 2019) and the MRC Council Study (MRC 2017). Here, the distribution, status and trends in fisheries are summarised to underpin the fisheries ecological and fish passage components of the review. Much of this summary is directly based on information provided for the Pak Beng HPP fisheries TRR, and is equally applicable to the LPHPP review.

3.1 Fish biodiversity and migration

The Mekong fish communities are characterised by high diversity of species (more than 1000 have been listed in the MRC species list: MRC 2017; Kano et al. 2013), with many exhibiting complex life cycles that involve migration between different areas of the river. Given the high diversity of species and complexity of their life cycles, the species are nominally categorised into 10 guilds based on their main habitat requirements and migratory traits, plus an additional category for non-native invasive species (Annex 3). These include a number of migratory ‘guilds’ that move up and downstream along the mainstem of the river and/or into tributaries to complete their life cycles, thus maintaining longitudinal connectivity within the river system is essential to conserve biodiversity and maintain fish population structure and abundance. With reference to the zone of influence of LPHPP, the main migratory guilds present are long (G2) and short (G3) distance migratory white fishes, grey fishes (G4) and anadromous species (G8). In addition, there is also a very important guild, rhithron species (G1), which are species resident in the local area and inhabit shallower riffle zones. This latter group is important both in terms of the number of species (Table 3-1), but also their contribution to the catches (Figure 3-3).

Table 3-1. Contribution of different fish species guilds to diversity in different zones of the upper Mekong in Laos (after MRC Council Study MRC 2017)

	Guild categories										
Ecological zone	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	Total
FA1	67 (44)	9	41	29	19	20	2	1	1	0	20	209
FA2	83 (38)	11	68	58	28	32	2	1	1	0	12	296
FA3	77 (31)	11	73	57	30	32	5	1	1	0	13	300

The general understanding of fish migration patterns in the Mekong is that there are three main systems (Poulsen et al. 2002a): the lower zone below Khone Falls, the zone upstream from the falls to Vientiane and the third zone upstream of Vientiane (Figure 3-1), and this is acknowledged in the LPHPP EIA report. However, there are also many species that migrate between these zones, and some species (possibly as many as 30 and mostly commercially valuable white fishes) that migrate longer distances (Poulsen et al. 2002a) between zones, and require unobstructed passage upstream, as well as the capacity for adults, larvae and juveniles to migrate or drift downstream. This includes at least one anadromous species, *Pangasius krempfri*, which migrates from the ocean to upper Laos into the zone of influence of LPHPP.

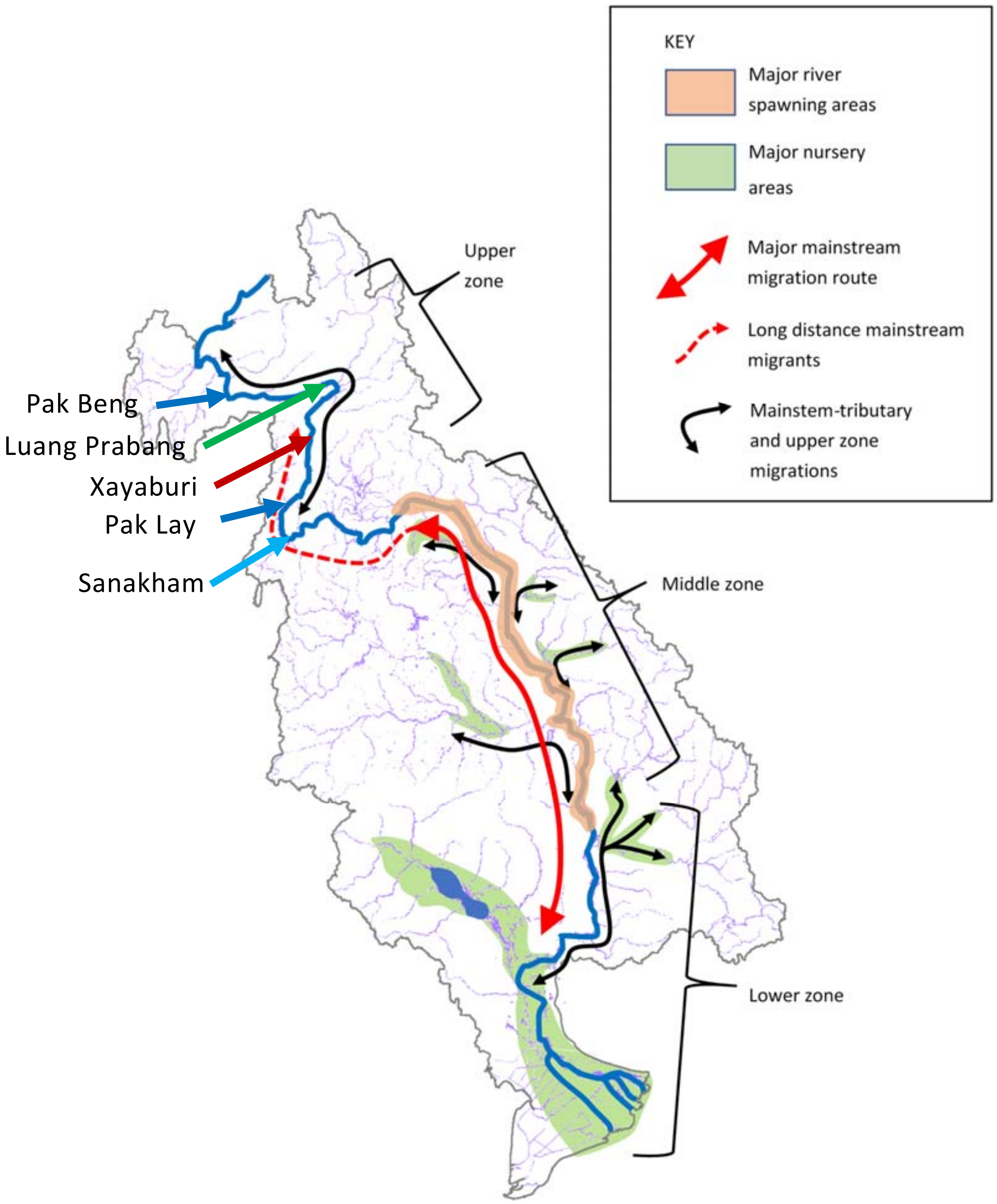

Figure 3-1. Map of migration systems in the Lower Mekong Basin (Source: DG2018)

The importance of this region for migratory whitefish species has also been confirmed by fish larval drift studies carried out by the MRC throughout the LMB (Cowx et al. 2015; Hortle et al. 2010). These studies identified that large numbers of Cyprinidae, *Micronema apogon, Pangasius macronema*, *Macrognathus siamensis* and *Mystus atrifasciatus* larvae drift downstream through this reach, including during the dry season: note the numbers caught suggest that downstream drift in the dry season could be equally as important as the wet season.

The timing of these upstream and downstream migrations is variable depending on fish life cycles (Table 3-2) and appears to mostly driven by the flood cycle (Figure 3-2), but importantly, there appears to be continuous spawning in the river with peaks during the spring (February-March) as the most important, followed by the onset of the flood (June-July) and then when the water is receding (November).

The LPHPP site and reservoir area are located in Zone 1 of the Mekong's Ecological Reach (MRC 2010), which is associated with the spawning habitat of several important species, including the endangered Mekong giant catfish and *Probarbus jullieni*. Although the precise number of species in the region is unknown, 209 species are indicated to be present in the MRC's fish species database (Table 3-1). However, it should be recognised that many species, especially of the Rhithron guild (Guild 1), are exclusively found in the headwaters of tributaries and are not found in the impact area. In addition, fish catch monitoring carried out by LARReC between 2007 and 2013 (Phouthavong & Boualaphanh 2015) found about 70 species caught in gill nets alone. These records are consistent with the number of fish species (81 fish species from 18 families) recorded in the LPHPP EIA.

Table 3-2. Summary of timing of fish migrations through LMB (Source: Baran 2006)

Season / Month	December	January	February	March	April	May	June	July	August	September	October	November	December	January
Type of fish migration														
Medium-sized cyprinid carps	X	X	X											
Small cyprinid fish (minnows)		X	X	X										
Large carps					X									
Catfishes (*Pangasius macronema* from Cambodia to Laos)					X	X								
Catfishes (*Pangasius krempfi* from Vietnamese Delta up into Laos) *P. conchophilus*						X	X							
Large fish (Mekong giant catfish)								X	X	X				
Endangered Probarbus jullieni											X	X	X	X

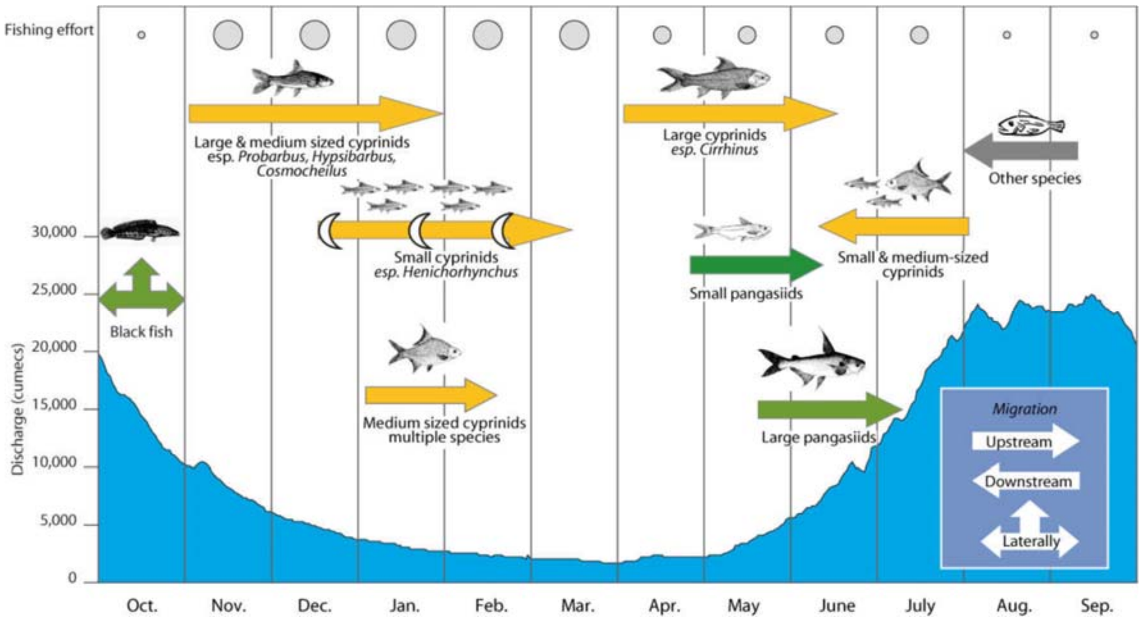

Figure 3-2. Fish migration patterns at Khone Falls, in the lower Mekong River (Baird 2001)

The immediate footprint of LPHPP is the barrier effect created by the dam infrastructure and the impoundment, which extends some 156 km upstream and changes the hydraulic conditions of the river environment and results in loss of rapids and fast flowing sections of river. Of particular concern, is the impact on rhithron and long and short distance migrating whitefish species (Guilds G1, G2 and G3), which make up the majority of the catch in the reach associated with LPHPP (Figure 3-3). Disruption of these migration pathways can be catastrophic, as has been predicted by the MRC Council Study using the DRIFT model (MRC 2017) and elsewhere (e.g. MRC ISH 306), and reference to this material is recommended. In addition, individual species such as the Mekong giant catfish and the anadromous species *Pangasius krempfri* are vulnerable to the dam development. Mekong giant catfish migrate from the middle Mekong Basin to spawn in the Upper Mekong Basin at Ban Had Krai, Chiang Khong District, Chiang Rai Province, Thailand and northern Lao around Luang Prabang between the end of April to May, and construction of LPHPP would obstruct migration. The dam itself will block migratory species and, as discussed below, the fish passage facilities are inadequate to maintain migration pathways in both upstream and downstream directions, and further potentially inundate the spawning habitats of these species. Furthermore, rhithron species will be lost from the impounded area as these species require flowing water habitats. Also of concern is the proliferation of non-native species, particularly common carp and Nile tilapia, which comprise a high proportion of the catch in the impact area, and it is likely these will benefit from the changed environment and expand further, possibly eliminating native species.

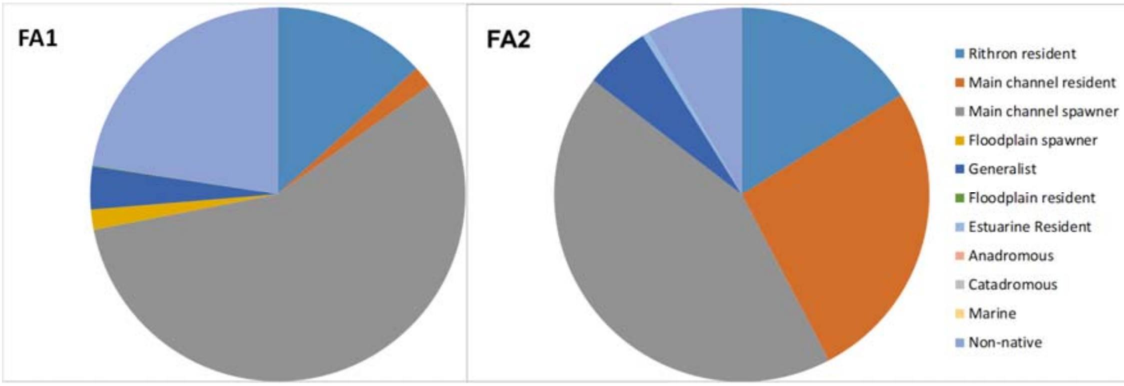

Figure 3-3. Guild contribution to weight composition of catch (data based on MRC catch monitoring surveys: MRC Council Study 2017).

The location of the dam will also likely inundate many deep pools that act as refuge areas for fish during the dry season (Poulsen et al. 2002b). How these deep pools will respond to the altered flow and sediment dynamics is unknown: the EIA acknowledges the run-of-river power plants will change the hydraulic conditions, but suggests the impoundment will provide more deep water areas. This is somewhat disconcerting because the impoundment area provides very different habitat with different functioning, the deep pools were predominantly refuge areas for fish during the dry season whereas the impoundment is a permanently inundated area.

Several fish species are listed on the IUCN Red List of threatened species, of which the following were recorded by IUCN as being present in the impact area:

- Critical endangered: Mekong Giant Catfish (*Pangasianodon gigas*), Giant pangasius (*Pangasius sanitwongsei*)
- Endangered (EN) species: Mekong stingray (*Dasyatis laosensis*), Isok barb or Julien's golden carp (*Probarbus jullieni*), thicklip barb (*Probarbus labeamajor*), dwarf botia (*Yasuhikotakia sidthimunki*), Laotian shad (*Tenualosa thibaudeaui*), marbled stingray (*Himantura oxyrhynchus*).
- Vulnerable (VU) species: small scale mud carp (*Cirrhinus microlepis*), mrigal carp (*Cirrhinus cirrhosus*), Mekong tiger perch (*Datnioides undecimradiatus*), elephant ear gourami (*Osphronemus exodon*), hairy puffer (*Tetraodon baileyi*).
- Near Threatened (NT): Boeseman croaker (*Boesemania microlepis*), long pectoral-fin minnow (*Macrochirichthys macrochirus*), great white sheatfish (*Wallago attu*).

Unfortunately several of these species are missing or have been misclassified in the EIA (Table 4.13). For example, IUCN RedList lists *Pangasius sanitwongsei* as critically endangered, *Probarbus labeamajor* as Endangered but these species are listed as data deficient in the LPHPP EIA Table 4.13. Worryingly, *Cyprinus carpio* (common carp), a non-native invasive species, has been listed as Vulnerable in Table 4.17.

3.2 Fisheries activities

Considerable fishing activity takes place in the impact area, mainly based on the migratory fish species, using an array of fishing gears such as lift nets, gill nets and range of other fish traps. It is estimated (MRC 2015) that some 40,000-60,000 t/yr of fish are caught in the river system in the upper LMB zone 1. In terms of the Basin fisheries, this upper part of the Mekong is not as productive as the middle and lower Mekong zones, which together produce approximately 2 million tonnes of fish per year (Figure 3-4). This production in the upper LMB Zone 1 is, however, highly likely this production will be compromised by the construction of Luang Prabang. The LPHPP is the 4th HPP in the upper cascade to undergo prior consultation. As the other HPP are constructed these impacts will be multiplied, and it is estimated that there will be a 40% reduction in short distance migrating whitefish (MRC Council Study 2017). Although there is a proliferation of non-native common carp and tilapia from fish farms in the markets, which could potentially substitute for any loss of the capture fishery, it is unlikely this source of fish will benefit rural communities in terms of loss of fishing activity or food security. This is especially true for rural communities that will not have the capital or revenue to establish aquaculture production units.

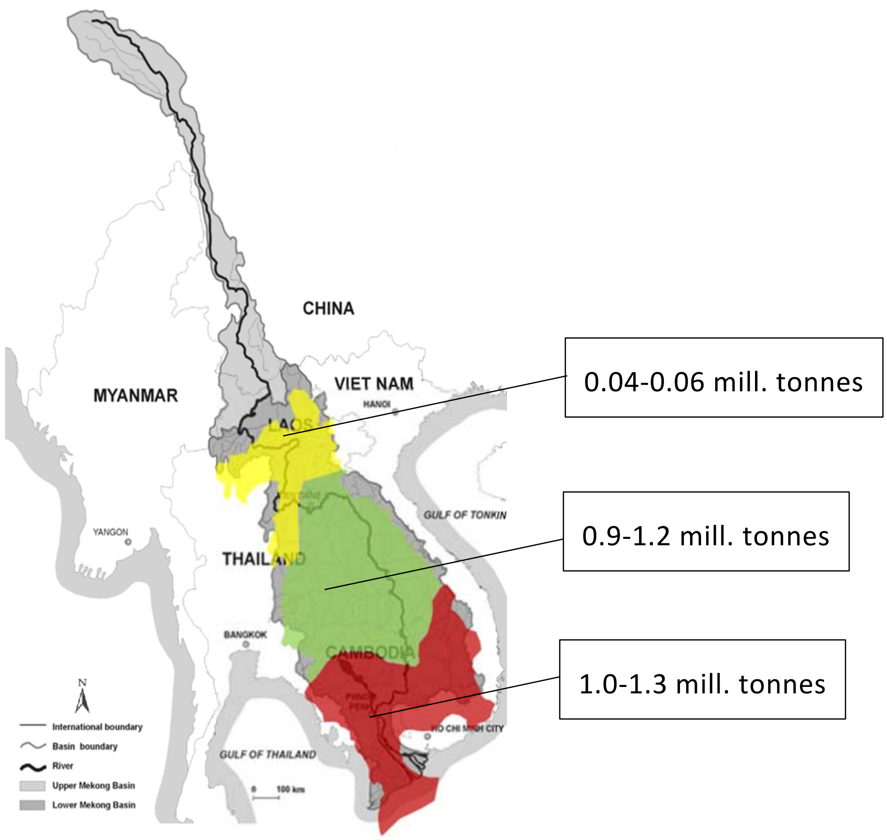

Figure 3-4. Zones of the Lower Mekong Basin and annual fish catch (MRC 2007).

Fishing generally occurs during the period of upstream migration of many species, and is associated with increasing water levels during the onset of the rainy season. However, these species are not the only ones captured; a wide diversity of finfish species is found in the markets (Figure 3-3.), including the non-native species, plus a range of amphibians, snails and Crustacea (OAA). It should be noted these latter groups are discussed in the CIA-TBIA as an important source of food, but the scale and value of this contribution is inadequately defined.

In addition, considerable fishing activity takes place in the tributaries associated with this region and thus isolation of these tributaries or flooding out of the habitat will likely compromise the wild capture fisheries and the livelihoods of the people that depend on them. This is particularly pertinent in the Luang Prabang region as the rural communities mainly fish in the tributaries, although it should be noted these tributaries have been largely compromised through construction of hydropower dams, none of which have fish passage facilities.

3.3 LPHPP fisheries studies

3.3.1 Fisheries ecological and socio-economic studies

The fisheries assessment in the LPHPP documentation comprises:

- a review of the fisheries literature for the Mekong concentrating on the reach in the upper Laos in the zone of influence,
- surveys carried out at five sites in the locality of the proposed LPHPP dam in February, June, September and November 2019;
- supplementary market and household surveys in the area also in February 2019;
- previous studies carried out for the Xayaburi (2010) and Pak Beng (2013) Prior Consultation processes, and surveys carried out by the XHPP developer as part of the concession agreement (2012, 2013 & 2018).
- LPHPP Baseline fisheries monitoring: from 1st field investigation report to 4th field investigation report,
- Initial observations on Xayaburi HPP fish pass monitoring.

The literature review highlighted that the Mekong River basin has the second largest biodiversity for any river basin following the Amazon Basin, but did not stress that it is by far the largest inland fishery globally with an estimated value in excess of $7 billion (Nam et al. 2015), rather citing the outdated $150 million of Hortle et al. (2013) for the whole of Lao PDR. They suggest that there are “781 species…722 native species, 21 endemic species, 10 introduced species, 26 questionable species and 2 misidentified species” (after World Fish Centre 2011), but these figures are inaccurate and outdated and have been superseded by the MRC Council Study (MRC 2107) using regional fish biodiversity experts (see Table 3-1).

The reports recognize the importance of breaking down the species composition into guilds, but only categorises into three guilds (migratory white fishes, grey fishes and black fishes), and minimizes the contribution of blackfishes because this zone of river has negligible floodplain waterbodies. However, this simplified **categorization does not account for the contribution of rhithron species and non-native species to the fish community structure or, importantly, to catches** (EIA, Table 3-1; Figure 3-3) or the contribution of diadromous species. It should be noted the rhithron species will likely be lost in the region if the cascade of dams is constructed**.** It should be noted the following species were categorised as whitefish but are in listed as rhithron species (G1) by MRC and other regional experts: the cyprinds *Epalzeorhynchos munense, Garra fasciacauda, Lobocheilos davisi, Lobocheilos melanotaenia, Mekongina erythrospila* (M), *Onychostoma meridionale, Opsarius pulchellus, Poropuntius krempfi, Tor sinensis* (M), and the Sisoridae *Bagarius bagarius.* (M indicates the species are medium sized.)

Further, there are inaccuracies in the naming of species (e.g. species of the taxa *Henicorhynchus* are now *Gymnostomus*) in various LPHPP documentation, including naming a new species - *Ompok euginiatus* - that is unknown in internationally recognised species lists such as FishBase. The LPHPP EIA (Table A2) has also included several non-native invasive species (*Cyprinus carpio* [common carp], *Labeo rohita* [Indian major carp - rohu] and *Belodontichthys dinema* [Malaysian toothed catfish] as whitefish. This is worrying because these species, along with *Oreochromis niloticus* [Nile tilapia], are likely to exploit the altered environment in the impoundments. The species have probably escaped from fish farms and floating cages in the region, and now contribute a significant, and increasing, proportion of the catch by weight. Note, no adjustment to account for these inaccuracies has been made in additional information provided in March 2020.

As indicated above, the LPHPP site and reservoir area are in Zone 1 of the Mekong's Ecological Reach (MRC 2010), which is associated with the spawning habitat of several important species, including the endangered Mekong giant catfish. Although the precise number of species in the region is unknown, 209 species are indicated in the MRC's fish species database. However, many species, especially of the rhithron guild (Guild 1), are exclusively found in the headwaters of tributaries and are not found in the impact area. Fish catch monitoring carried out by LARReC between 2007 and 2013 found about 70 species caught in gill nets alone. These records are consistent with the number of fish species (81 fish species from 18 families) recorded in the LPHPP EIA in February 2019 and the cumulative number of species (107) found in four surveys conducted in 2019. Insufficient time was available to assess fully the fisheries catch data provided in March 2020 for presumably seine net surveys from the months February, June, September and November, however, there are seasonal changes in the fish species composition and this should be reflected in the baseline reporting by the developer.

There is a clear need to evaluate the status of the fish species in the region using the ten guilds based on migratory and main habitat use (Appendix 2), **to reflect the true composition of different species groups.**

The Developer's review draws on MRC information to highlight that the fisheries are highly dependent on migratory species. However, the reports seem to assume that migration of fish is largely restricted to within the upper migration zone (Vol 1 Exec Sum p27; Vol 5 CIA-TBIA Section 5.5.3), and even go on to say fishes migrate upstream of Pak Beng for spawning (Vol 1 Exec Sum p27). These interpretations are not accurate as there is known to be migration of fishes between all zones, and at least one anadromous species (namely *Pangasius krempfi*) migrates from the sea to the Luang Prabang region and the Mekong giant catfish also possibly migrates from Cambodia to Laung Prabang region. Reference to the MRC Council Study will better inform the assessment of migratory patterns.

One aspect that the LPHPP review stresses is the importance of downstream larval drift (Vol 4-1 EIA, Section 4.3.5.2). This is entirely based on the larval drift study of Hortle et al. (2015), because the larval drift sampling carried out at six stations (Vol 4.1 EIA p 83: noting only 5 stations were used for WQ and fish sampling) from 24-26 February 2019, as part of the pre-assessment, failed to catch any larvae. The lack of catch is possibly due to weakness in the sampling protocol and it is recommended that the developer refers to methodologies described in Cowx et al. (2015). Moreover the sampling was done during the period when few species breed and thus there is little likelihood of catching larval life stages. Irrespective, the review clearly stresses that huge numbers of larvae (hundreds of millions and likely many more) pass downstream and this trait must be accommodated in any mitigation measures, particularly ensuring adequate flow is persistent through the whole length of the impoundment to keep the larvae suspended in the water column and thus maintain recruitment dynamics throughout the LMB. **Larval drift studies similar to those carried out by the MRC over the annual cycle should have been carried out by the developers to understand the importance of the impact area to fish recruitment processes, and equally importantly how the change in hydraulic conditions in the impoundments will affect downstream drift, a critical life history tactic of many Mekong species.**

The LPHPP review draws explicitly on the abundance of fisheries-related data collected over the construction period of Xayaburi HPP, as well as information from the Pak Beng Prior consultation. This is a rich source of information and is highly relevant to the LPHPP consultation. The numbers of species reported in these various studies was consistent with the LPHPP reports (Vol 4.1 EIA Table 4-14), except considerably more species (120 compared with approximately 60 at other times or locations) were reported as a result of the intensive survey programme carried out at Xayaburi in 2013. This clearly shows the inadequacies of the limited fish sampling programmes carried out as part of the LPHPP and other prior consultations, and the possibilities of drawing inaccurate assessment of the impact of the dams on fisheries resources and biodiversity.

Further, the review of previous intensive studies at Xayaburi highlights the huge biomass of fish that can pass upstream during the migration. Up to five tonnes of fish were found to pass per hour over a six-hour period on 3 May 2012, which gives an indication of the volumes of fish that any fish passes at LPHPP must accommodate, and this estimate of biomass passing upstream is likely a conservative estimate.

The four fisheries surveys were carried out at the same time and locations as the water quality monitoring. There is no indication of the sampling methods, but it is assumed to be either gillnetting or seine netting, both of which are highly selective. A total of 534 individuals, (dominated by a single species - *Sikukia gudgeri*) from 81 species, representing 18 families were caught in February 2019 and 2206 individuals representing 107 species (again dominated by *Sikukia gudgeri*) from 4 surveys carried during 2019 (February, June, September and November). The diversity reflects that expected from the region, but the number of individuals caught was low and inadequate for any robust assessment of the baseline status of the fish community and population structures.

The fisheries catch assessments were supported by fish species surveys at local markets and interviews with 10 fishermen from five villages, the latter of whom largely indicated the best time for fishing, gears used and how they disposed of their catch, but they were not consulted on recent trends in catches, especially since the construction of Xayaburi HPP.

In March 2020, additional information was received of ARIS hydroacoustic camera surveys at LPHPP. These surveys were conducted for 8 days each month from February to May 2019 and provided counts of fish passing up- and downstream passed fixed points broken down into day and night (Table 3-3). Thousands of fish were recorded, mostly passing upstream, but with a more than doubling of number in May 2019 compared with other months. There appears to be no relationship between numbers moving upstream and discharge, and this movement is most likely linked to reproductive migration. Although the information provides insights into the movement of fish, there are limitations of the data. No information is given of the proportion of images captured in different ranges of ARIS. No information is given of the species imaged, just size of individuals, which were mainly in the 10-20 cm size range. No interpretation of the information is given or more recent data provided to show annual trends. Further, it should be recognised that ARIS does not register fish moving along the bed of the river, thus not accounting fully for benthic species, and no account made of fish milling around the image area, thus duplicate counting or recording the same fish moving up and downstream.

In addition, information was also received of initial observations on Xayaburi HPP Fish Pass Monitoring. These data were an inventory of species caught at Xayaburi fish pass, but do not provide any quantification of numbers caught or temporal variability in data and timing of movements about the fish pass.

Table 3-3. Numbers of fish counted moving up and downstream in ARIS surveys in February, March, April and May 2019.

Dates	Width (m)	Depth (m)	Discharge (m^3/s)	Number of fish	
				Upstream	Downstream
15-23 Feb 2019	135	27	1580		
Number of fish				8025	824
% size 10-20 cm				75	54
% moving during day				93.3	73.3
6-14 March 2019	N/A	N/A	N/A		
Number of fish				9728	3754
% size 10-20 cm				70.8	22.2
% moving during day				95	62.5
2-10 April 2019	151.7	28.67	3360		
Number of fish				6832	431
% size 10-20 cm				83	51
% moving during day				90	44.8
6-14 May 2019	151.7	30.7	3120		
Number of fish				19062	1569
% size 10-20 cm				46	56
% moving during day				87.1	48.2

The EIA provides a review of endangered and vulnerable aquatic organisms, mostly fish species, in the area and suggests potential impacts could arise from the obstruction to migration and change in environmental conditions. It does not, however, suggest that these species will require special studies and management plans. There are also inaccuracies in the IUCN threatened status of several species. For example *Pangasius sanitwongsei* as critically endangered, *Probarbus labeamajor* as Endangered but these species are listed as data deficient in the LPHPP EIA Table 4.13, and *Cyprinus carpio* (common carp), a non-native invasive species, has been listed as Vulnerable in Table 4.17, yet it is an invasive species. One of the biggest impacts recognised, in addition to the major barrier created by the dam, was the change in hydraulic conditions upstream of the dam and the potential loss of deep pools in the impounded section. The EIA suggests the impoundment will, however, provide more deep water areas, but does not recognise the impoundment will be very different environment with a different functional role.

The SIA suggests that fishing is not the main occupation among local villagers in the project area, yet between 24 and 50% of households are engaged in fishing (Vol 4-2 SIA Table B-1-100, and no indication of the contribution of fishing to income or food security is provided. It should be noted that interviews with households during the field visit to the dam site on 4 December 2019 found that most households fished for food, especially during the peak fishing season, but very few considered themselves full time fishers. A few households have fishponds / tanks, presumably as some part of a fish farming activity, but the income generated is minimal. This suggests that that some households may have the skills, but not necessarily the resources or infrastructure, to farm fish should the need arise.

3.3.2 Fisheries Impact Assessment

An extensive review of the fisheries in the LMB is provided based on literature but it does not make use of the comprehensive information provided in the MRC Council Study or the MRC fisheries database. For example, the MRC's Council Study estimated that a 40% reduction in short distance migrating whitefish was likely as result of construction of dams in the upper Lao cascade. Furthermore, baseline monitoring of the fish and fisheries carried out by the developer is inadequate and based on a superficial sampling programme covering 5 sites sampled in four separate months (February, June, September and November), but the data have not been analysed beyond species and count. The data are insufficient to establish baseline conditions. As a consequence, the EIA relies more on the literature review and data gathered during the development of Xayaburi HPP and prior consultation for Pak Beng than for this specific development. Reported species diversity was consistent with that expected for the region but no robust empirical measure of abundance and biomass of each species was provided. The study of fish larvae drift and juvenile life stages is inadequate and relies on the study of Hortle et al. (2015).

The loss of spawning and nursery habitat for migratory and rhithron fish species in the region caused by the 156-km long impoundment needs to be evaluated. Although it was originally suggested in the MRC HEC-RAS model that a small stretch of river would remain free flowing, this now appears not to be the case with a proposed operating level of 275 m asl at Xayaburi. In Section 6.1 of the CIA-TBIA report, it is clearly stated that: "Upstream and downstream of the dam the hydraulic conditions change. The back-water effect of Xayaburi HPP defines the tailwater level at LP HPP and therefore no river section remains, that has natural flow conditions." Nonetheless, the LPHPP developers indicate that new hydraulic models suggest that a limited reach of river between the Xayaburi head water and LPHPP tail water would be maintained, but these model outputs have yet to be received and evaluated. Irrespective, the free-flowing reach of river downstream of LPHPP dam will likely be impacted because the bed will erode and will become rocky and incised because the river will be starved of sediment locked in the dam. The backwater of Xayaburi may then have even bigger influence. The loss of habitat and lack of access to tributaries may lead to shifts in species composition and the composition of fish catches. Importantly it is thought that the region around the Nam Khan confluence is a spawning area for the Mekong giant catfish that will likely be lost, and this has not been considered.

The developer notes that fisheries will be adversely affected by the disruption of migration and potential loss of endangered and threatened species, both during the construction and operational phases, but little attempt has made to relate the fisheries stock dynamics to environmental changes brought about by the development and operation of the scheme. Modelling of the likely changes in structure and functioning of the in-channel habitat features should be developed to predict likely changes in the fish population and community structures and overall impact on the fisheries.

No monitoring programme for fish passage is described. This is essential to enable evaluation and adaptive management of the fish passage facilities. This issue is discussed further in Section 5.

Recommendations:

- **A robust fisheries monitoring programme must be set up to collect baseline data and information during the final design phase. The programme must be designed to assess any potential impacts, and to propose effective impact mitigation measures for fish migration and spawning, or perhaps alternative mechanisms to maintain people's livelihoods, including offsetting, should the potential cascade of dams cause irreversible damage (see Section 5).**
- **Data and information from the MRC's Fish Abundance and Diversity Monitoring and the MRC Council Study - Biological Resources Assessment Technical Report (MRC 2017) should be used to further inform this process, as well as the design of the fish passage facilities – both for upstream and downstream migration.**
- **Further, an assessment of the potential impact of altering the critical habitat in the vicinity of the dam by the loss of access to, and inundation of, upstream riffle reaches that act as spawning and nursery areas, including for rhithron species, needs to be evaluated.**

3.3.3 Socio-economic importance of fisheries resources

The EIA, CIA-TBIA and SIA describe the importance of the fisheries resources (i.e. fish, other aquatic animals, and useful aquatic plants) to the livelihoods of the people both in the LPHPP impact area and elsewhere in the LMB. Consequently, any risks and losses brought about by dam developments potentially translate into threats to livelihoods and potentially food security of local communities. However, it was concluded that fisheries are not important to the region where the LPHPP is planned, thus the effect of the dam on the fishing communities would be limited around the dam area. These two conclusions are incongruous and the importance of fish to food and nutritional security in the LPHPP area seems to be underestimated. This is was highlighted during the field visit to the dam site on 4 December 2019, when most households were found to consume fish caught locally on a daily basis,

The CIA-TBIA (Vol 5 Section 5.5.1) gives some indication of the importance of fish as a source of food in Lao PDR. This is based on Hortle et al. (2013) and just provides figures for consumption in Laos as whole. These data are outdated and the figures of So et al. (2015) and the MRC Council Study (MRC 2017) would provide a better reflection of the importance of fish to diets in the LPHPP impact area. The CIA-TBIA also attempted to make an approximation of the fish that would be produced in the impoundment to compensate for the lost river fisheries. The crude calculation, based on surface area of the impoundment and production per unit, suggests 343 t of fish would be produced and would feed 14,000 persons, or half the population of Luang Prabang. This is an extremely misleading calculation. LPHPP is a run-of river scheme so primary productivity of the reservoir will be minimal as the retention time in the reservoir is only a few days, thus limiting capacity for primary production – the food base. Also fish consumption in the region is much higher than the 24.5 kg/year/person cited. Finally this calculation does not account for the nutritional importance of fish to the diets of local people: fish is the primary protein source and provides many of the essential micronutrients required for a healthy diet. This concept needs re-examining as there are numerous assumptions about the source of the fish, standing stock biomass of fish in the region, consumption rates, and the analysis does not recognize the contribution of migratory species.

Unfortunately, there is limited information on the socio-economic importance of the fisheries to food security and rural livelihoods, number of people affected, and loss of ecosystem services to rural communities. What information is available is largely contradictory and fragmented, and insufficient to provide a baseline on socioeconomic importance of fisheries and OAAs, or indeed non-forest products, to people living in the mainstream hydropower project-affected area. The developers should have undertaken more extensive surveys, at least monthly, to monitor fishing activities and instigated catch assessment and market surveys to improve understanding of the importance to the rural communities in the impacted area around Luang Prabang.

4. REVIEW OF FINDINGS OF FISH PASSAGE FACILITIES – IMPACTS AND MITIGATION

4.1 Introduction

As discussed above, many species migrate through the upper reaches of the LMB. As a consequence, any evaluation of impacts of dams needs to consider all factors impacting on the fisheries in a consolidated manner. Thus, since the Luang Prabang HPP (LPHPP) is immediately upstream of the Xayaburi and Pak Lay HPP any fish passage considerations will need to consider these dams together. While the downstream migration must accommodate the impacts of the Pak Beng HPP. In particular, lessons from the construction and initial operations of the Xayaburi HPP can be applied to LPHPP.

This section firstly outlines the principles of fish passage design to provide some background (sec. 4.2). The Luang Prabang Hydropower Project (LPHPP) is then reviewed in detail (sec. 4.3), providing each issue with a summary of recommendations and a risk (consequence) score (Table 4-1) if the issue is not addressed. The objective of the risk score is to aid comparison of the issues and identify which are high priorities. A more complete risk analysis is provided in section 4.4.

Table 4-1. Risk (Consequence) scores.

Consequence
Critical
Major
Moderate
Minor
Insignificant

4.2 Principles of Fish Passage Design

4.2.1 Background

Attraction and Passage

Some key principles of fish passage design are outlined here to serve as background to the present review. In fishway or fishway design, whether technical or nature-like, there are two essential functional criteria:

i. *attraction* (i.e. the fishway entrance), and

ii. *passage*

These criteria are completely interdependent: if fish are not *attracted* to the fishway or cannot locate it, they cannot use it; equally, if they can locate the fishway but passage conditions are inadequate (shallow water or high water velocities beyond swimming capacity) fish also cannot use it.

Effective *attraction* is dependent on three characteristics:

i. *Proportion of flow*

The higher proportion of river flow in the fishway the greater the attraction for fish.

ii. *Upstream limit of migration*

Migrating fish swim upstream, attracted by the flow, to the *limit of migration*; this is where a fishway entrance needs to be located. A good example of using this aspect of fish behaviour in the Mekong River, is the location of lee traps by fishers at Khone Falls, which are adjacent to natural migration barriers.

iii. *Discrete flow for fish to locate*

The flow from a fishway needs to be readily distinguishable to migrating fish and not masked by turbulence or competing flows.

Effective *passage* is dependent on knowledge of:

i. *Fish behaviour*

Fish behaviour relates to *attraction* and *passage*. In *attraction*, it includes search patterns below a structure, response to turbulence, and response to different channel morphologies.

In *passage* an important aspect is the minimum depth that fish require; this is not a single figure but interacts with width (e.g. channel width) and longitudinal spacing of different depths (e.g. resting pools may need to be deeper). Other behavioural aspects that can be important include the response of fish to light and tunnels, and diel movement patterns.

ii. *Swimming ability*

In rivers, channels and fishways, fish negotiate water velocity and turbulence. In fish passage design these characteristics need to be within the burst, prolonged and sustained swimming ability of fish. These swimming modes utilise anaerobic and aerobic metabolism and they vary between sizes and species. There is also a behavioural element to consider where some species use boundary layers (layers of low water velocities adjacent to surfaces) more effectively than others.

4.2.2 Design process

The steps in the design process of fish passage are shown in Figure 4-1. Key aspects are understanding the variation in headwater (upstream water levels) and tailwater (downstream water levels) in relation to migratory flows and identifying areas where fish are expected to be attracted.

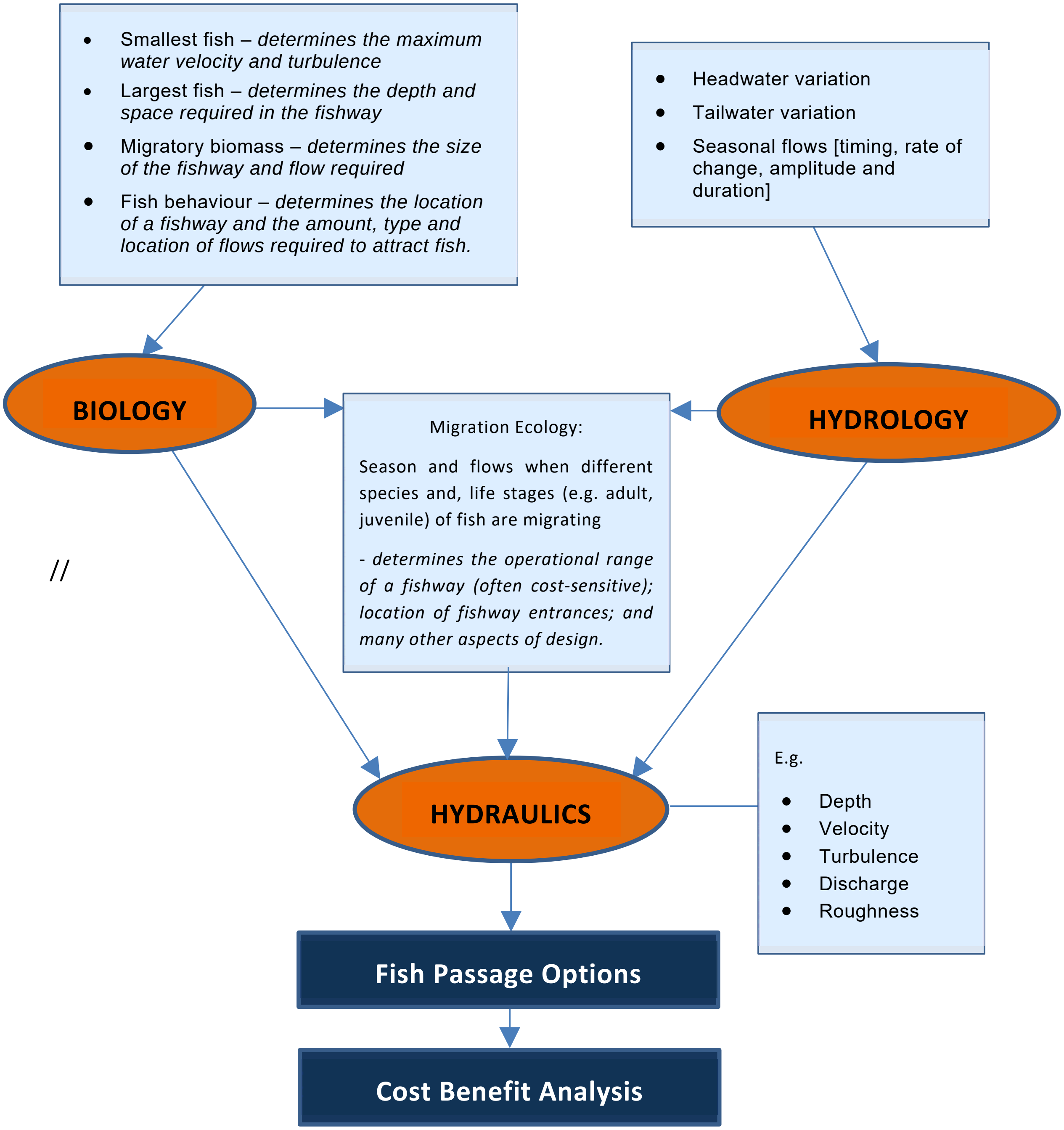

Figure 4-1. Process of designing fish passage.

4.3 Evaluation of Measures Proposed by Developer

4.3.1 Introduction to evaluating fish passage

Evaluating fish passage is like evaluating links in a chain: all links need to work for the chain to be effective. Firstly, fish passage needs to effective upstream and downstream; if fish cannot migrate one way, the life cycle cannot be completed and fish populations will slowly, or in some cases rapidly, decline.

Each component of the fish passage solution (upstream and downstream) needs to be equally effective; otherwise the weakest link will set the standard, and effectiveness, of the entire system. If, for example, *attraction* is inadequate for the upstream fish passage and fish cannot locate the entrance, then no matter how well the fishway facility at the dam is designed it will not be used and will be ineffective.

In the following evaluation each component is evaluated separately and then in the risk assessment (Section 4.4), the fish passage is evaluated as an entire linked system, to identify if there are weak links and risks to be mitigated.

4.3.1 Hydrology and Ecology – criteria proposed for fishway design

Design criteria on hydrology and ecology are provided in the documentation of the LPHPP. As described above (sec. *Design Process*) these aspects form the basis of fishway design and are reviewed here.

a) Season

The LPHPP has chosen to follow the MRC Draft Preliminary Design Guidance (PDG2019) with the objective of designing the fish passage facility to operate all year (within the operational flow range which is discussed in the next section). The decision is prudent given that the upper Mekong (Chiang Saen to Vientiane) fish migrations are inadequately studied, and in large tropical rivers like the Mekong there is generally some upstream migration all year round.

The most recent data from the Xayaburi HPP show high levels of upstream migration during the dry season and during the onset of the rainy season. The Xayaburi HPP used a ARIS underwater acoustic camera to survey migrating fish; the data are reliable at low flows but less certain at peak flows, as it is difficult to sample accurately and safely. Those data suggest a key season of upstream migration and can be used to identify periods of low migration when maintenance of the upstream fish passage facilities would have minimal impact.

There are few data on downstream fish migration in the upper Mekong. For adult and sub-adult fish, it is more likely to occur at any time after the peak upstream migration in the dry and early rainy season, and extend to the end of the rainy season. Hence the period of downstream migration could be from June to December, however, larvae have been found to drift downstream all year (Cowx *et al*. 2015). The LPHPP design objective, of fish passage all year, would accommodate this aspect of fish ecology in the Mekong.

SUMMARY

Issue: The LPHPP has the objective of designing the fish passage facility to operate all year, as per MRC Design Guidance.

Recommendations: No change.

Risk: Insignificant

b) Migration Flows

The LPHPP has chosen to follow the PDG2019 with the objective of designing the fish passage facility to operate from minimum flows to 1-in-1 Year Annual Recurrence Flow (ARI), which is 10,650 m^3/s. The minimum flow in the LPHPP hydrology report is 793 m^3/s, although it is 1,170 m^3/s in the fish passage design - the latter figures considers the increase in base flows due to the Chinese dams upstream but does not consider climate change. Further analysis is needed on climate change to confirm the minimum flow. As fish are migrating upstream in low flows during the dry season, the minimum flow is important for design and influences the tailwater level selected for the fishway and floor level (see next section).

Further analysis of changes to flow could change the estimate of future minimum flows. Note that the risk of underestimating minimum flows. Note that the risk of overestimating minimum flows in fishway design is very significant because it sets the minimum tailwater. *If the tailwater is lower than the minimum used for design,* ***the entire fishway*** *may not work as high velocities are created at the entrance which fish cannot enter*.

The upper flow range of 10,650 m^3/s is almost the same as the Xayaburi HPP fish passage facility; hence these two projects have the potential to operate in unison for fish migration. Given the upper flow range, the fish passage facility at LPHPP needs to accommodate three major hydraulic conditions:

i) Up to 5,355 m^3/s, when all water passes through the turbines.

Implications for fish passage

Upstream migratory fish will be attracted to the powerhouse. Almost all downstream migrating fish will pass through the dedicated fish bypass or turbines.

ii) Between 5,355 m^3/s and 10,650 m^3/s when both the spillway and powerhouse are operational.

Implications for fish passage

Upstream-migrating fish will be attracted to the powerhouse and spillway. Downstream-migrating fish will pass through the dedicated fish bypass, or turbines, or spillway.

iii) Flows greater than 10,650 m^3/s when increasing flow passes the spillway.

Implications for fish passage

Upstream fish passage facility would be operating sub-optimally, as per MRC PDG2019, and most downstream-migrating fish would be using the spillway.

SUMMARY

Issue: The proposed migration flows for fish passage design from minimum flows to 10,650m^3/s, which covers the anticipated migration period and matches the operating range of the Xayaburi HPP that is immediately downstream. The minimum flow for LPHPP is 793 m^3/s in the hydrology report and 1170 m^3/s for fish passage design.

Recommendations: Provide analysis of climate change impacts on minimum flow.

Risk if not addressed: Moderate

c) Headwater

Once the range of flows for fish migration is delineated, the headwater and tailwater ranges for the fishway can be determined. The LPHPP proposes a 0.5-m headwater range for upstream fish passage: from 312.0 to 312.5 m elevation[1]. A 0.5-m headwater range is very narrow and further consideration should be given to a wider range to allow for future changes to dam operation, particularly if consideration is given to draw down the impoundment at lower flows to promote downstream drift of eggs and larvae, and sediment flushing.

The headwater range will set the floor level of the fishway. For example, with a minimum depth of 3 m, the floor of the fishway exit would be at 309.0 m. If the reservoir were to be opeated at a lower level, such as 308 m, then the fishway exit would be dry. Such as scenario is very costly to retrofit a solution, but simple to address in design.

[1] The Pak Beng HPP developer has raised concerns that this raises the LPHPP backwater to the point where it may compromise their power output, and that this conflicts with the operating levels provided by the Government of Laos, which is 310 m asl. This is addressed in more detail in the hydrology annex. If the lower level is adopted the fish passage design would have to be adjusted accordingly.

SUMMARY

Issue: The proposed headwater range in the LPHPP of 312.0-312.5 m is considered appropriate, if the reservoir is operated within this narrow range.

Recommendations: Review future dam operation to ensure floor level of fishway exit is sufficiently low to accommodate future changes.

Risk if not addressed: Insignificant (if reservoir operated as planned).

d) Tailwater

The minimum tailwater for the LPHPP fishway is set at 276.70, which reflects a minimum flow of 1170 m^3/s.

The flow assumes past modelling of the Chinese cascade of dams and should be updated with climate change models to assess the minimum flow. The minimum flow in the past has been 793 m^3/s, as discussed above, and may ne lower than 1170 m^3/s . Therefore, the minimum tailwater level for the fishway design may need to be lower than the present design.

The minimum tailwater and minimum fishway depth of 3 m sets the floor of the fishway entrance. Hence, further analysis of the minimum flow is important for this design criterion.

The tailwater range for flows of 793 m^3/s to 10,650 m^3/s is approximately 12.43 m, from 277.0 m to 287.43 m elevation. For comparison, the Xayaburi HPP fishway is designed for 14 m of tailwater variation.

SUMMARY

Issue: The proposed minimum tailwater for the LPHPP fishway of 276.70 m may not reflect the minimum flow.

Recommendations: : Provide further assessment of the minimum tailwater combining models of the upstream Chinese dams and climate change.

Risk if not addressed: Moderate

4.3.2 Upstream fish passage

a) Attraction - entrance location

As discussed earlier, there are two essential functional criteria for effective fish passage: *attraction* and *passage*. *Attraction* relates to entrance location and conditions to ensure migrating fish locate the fishway.

The LPHPP fish passage facility has several entrances: i) along the top of the draft tubes of the powerhouse; ii) at each side of the powerhouse; iii) at the left-hand side of the spillway; and iv) on the right-hand side of the spillway (which is an addition to the Xayaburi design). At the concept level, these are all the key locations where fish would migrate to. At a more detailed level, as per the plans supplied, most of these locations need refinement or major modification.

The entrances on top of the draft tubes and to the sides of the powerhouse are well located for surface and midwater species over the flow range up to 5,000 m^3/s (Figure 4-2). However, benthic species and thalweg-oriented species (which use the deepest channel in the river), do not have adequate entrances (Figure 4-2). Some of these may ascend to the proposed draft tube entrances but some are unlikely to do so. Hence, it is recommended that additional entrances for these bottom-dwelling fish be considered. For example, these entrances could fit between the draft tubes, or the entrances on the sides of the powerhouse could have lower sills, while the thalweg should be shaped during construction to lead fish to these entrances (Figure 4-3).

The spillway entrances need to accommodate three main conditions: i) low spillway discharge when the low level outlets are used (Figure 4-3), ii) moderate spillway discharge when all spillway gates are partly open (Figure 4-4), and iii) high spillway discharge (e.g. 5,000 m^3/s through the spillway) (Figure 4-5).

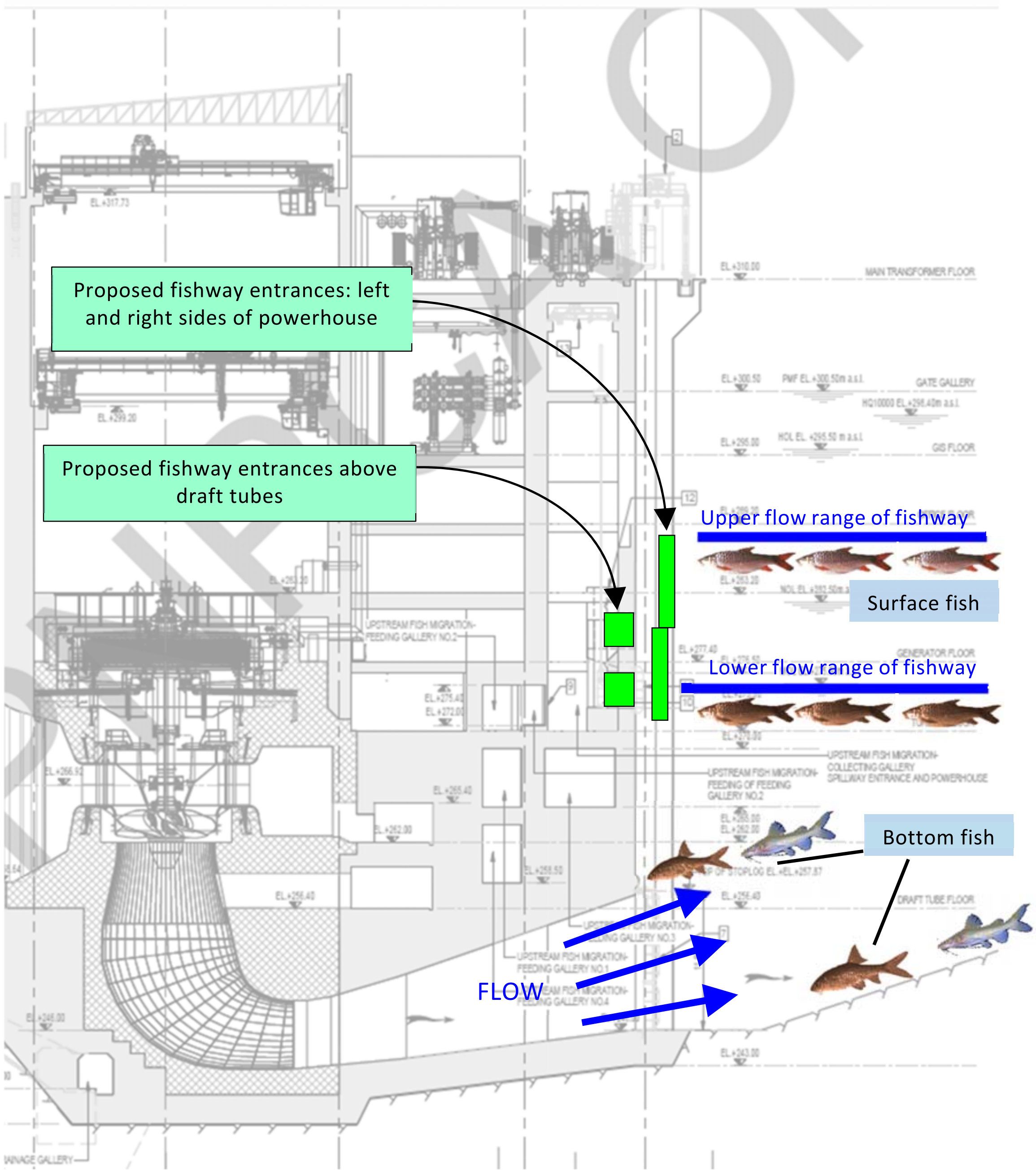

Figure 4-2. Cross-section of turbine and draft tube, showing fishway entrances above draft tubes (height to scale) and fishway entrance located to the right and left of the powerhouse (height to scale); with potential locations of surface-dwelling and bottom-dwelling fish (fish not to scale).

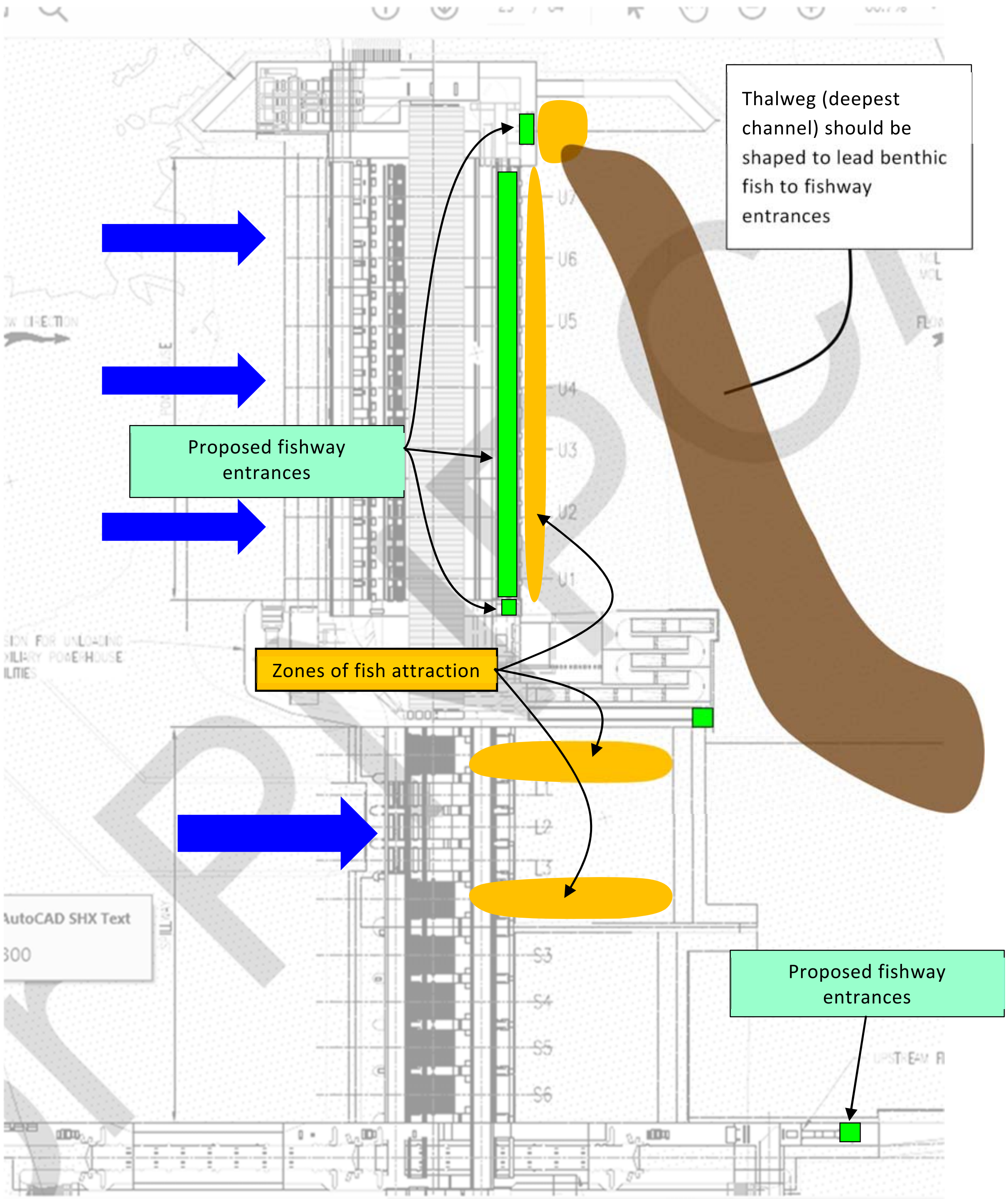

Figure 4-3. Plan view of powerhouse and spillway showing: fishway entrances (green) and zones of fish attraction (orange) at <u>low</u> spillway discharge with only low-level spillway outlets being used; and recommended shaping of thalweg (deepest channel).

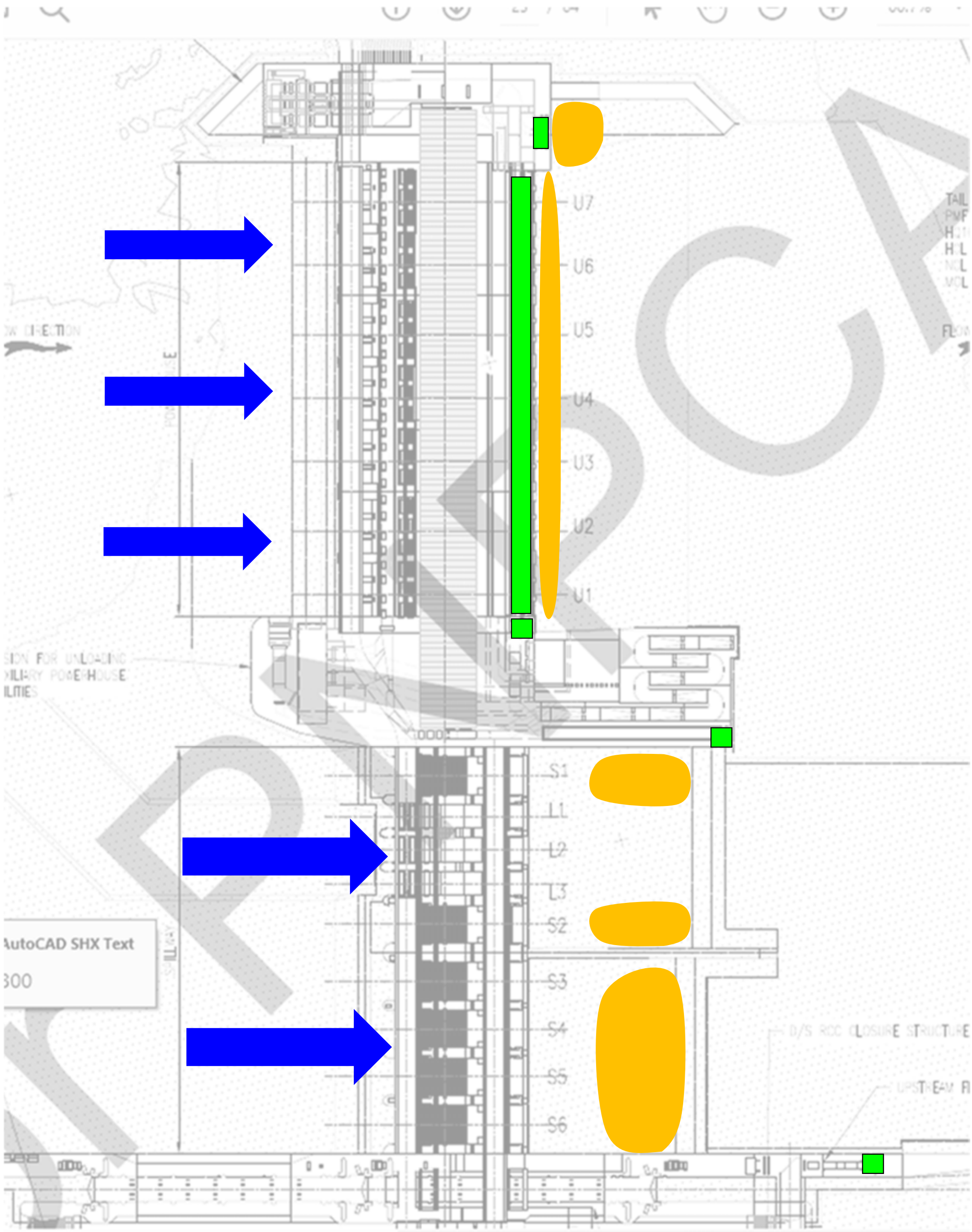

Figure 4-4. Plan view of powerhouse and spillway showing: fishway entrances (green) and zones of fish attraction (orange) at moderate spillway discharge.

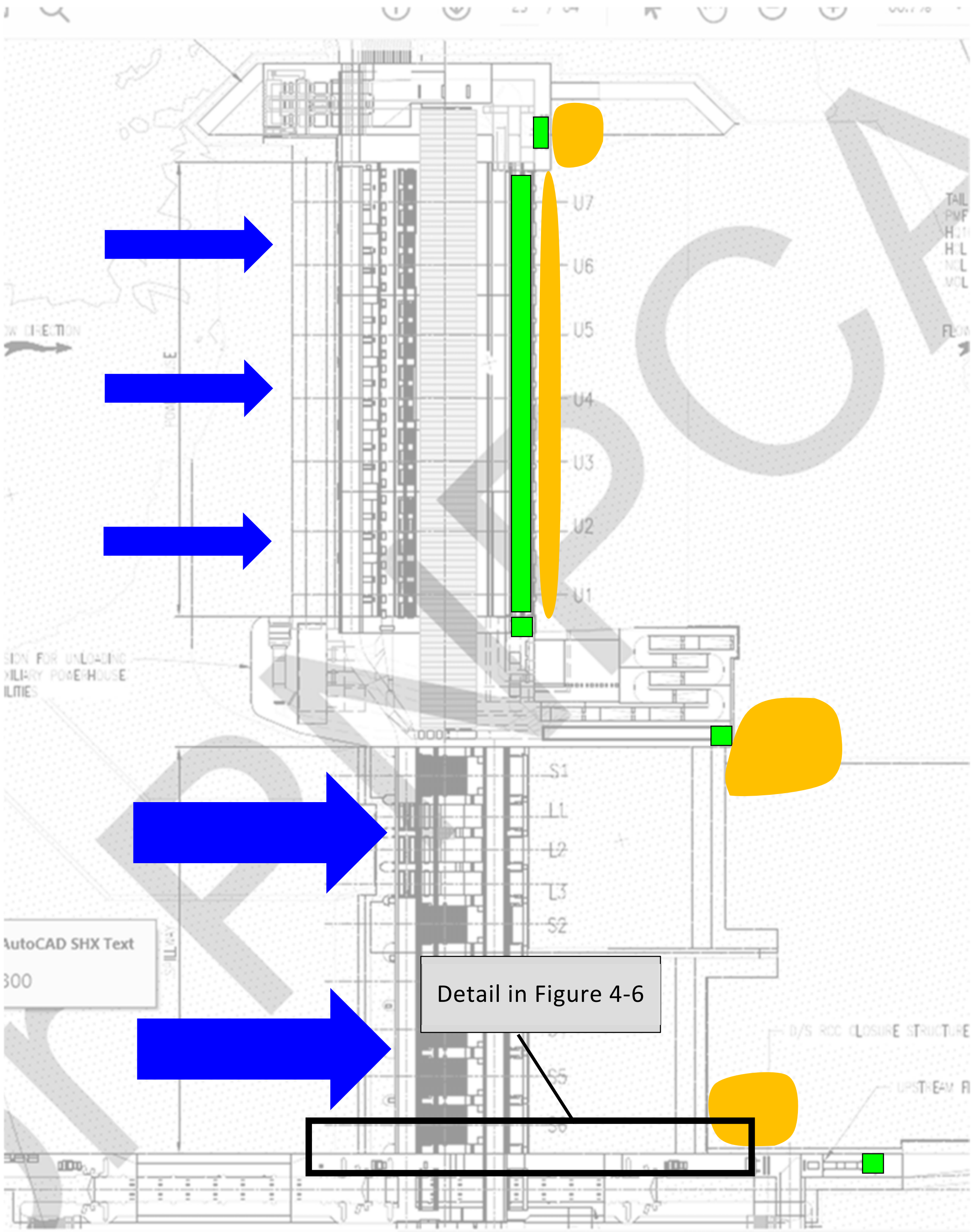

Figure 4-5. Plan view of powerhouse and spillway showing: proposed LPHPP fishway entrances (green) and zones of fish attraction (orange) at <u>high</u> spillway discharge.

When the low-level spillway outlets are used, the adjacent gates are closed and fish will swim to either side of the low-level gates (Figure 4-3). At moderate flows fish will be forced further down the stilling basin by high turbulence and at high flows fish are likely to be unable to access the stilling basin. At high flows, fish are likely to be at the end of the spillway as the flow pattern turns up and produces a lower turbulence area on the downstream upturned face of the stilling basin (Figure 4-6).

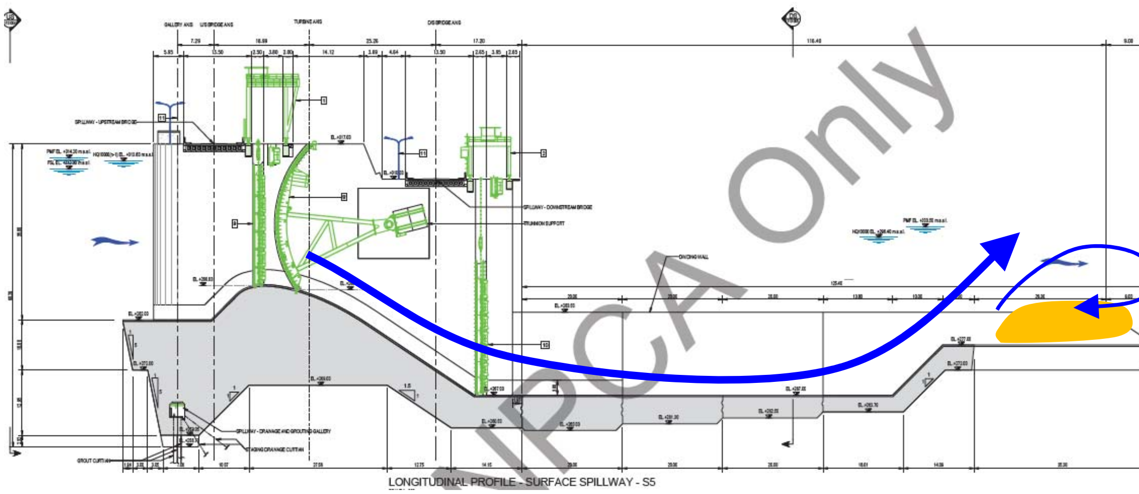

Figure 4-6. Cross-section of spillway showing potential flow pattern at end of spillway, with zone of fish attraction (orange) at high spillway discharge.

The LPHPP needs to investigate at least these three flow conditions in physical modelling to develop appropriate fishway entrances for different flows. Suitable scales for physical modelling are 1:100 for broad patterns and 1:20 for detailed flows and fishway entrances. To accommodate the different spillway conditions the spillway abutments will likely need to be shaped. Offsets in the abutment wall can create effective conditions for fishway entrance at different flows (e.g. Figure 4-7) and these should be tested in physical modelling at spillway flows up to 10,000 m^3/s, in increments of 500 m^3/s. In the present design the left-hand spillway entrance is well positioned for high flows, while the entrance of the fish lock at the navigation lock is inadequately positioned. This latter fish lock also has an entrance on the navigation lock side, which is presently not integrated with flows from the lock valves. In the LPHPP report it is noted that refinement of this entrance will occur in the Tender stage.

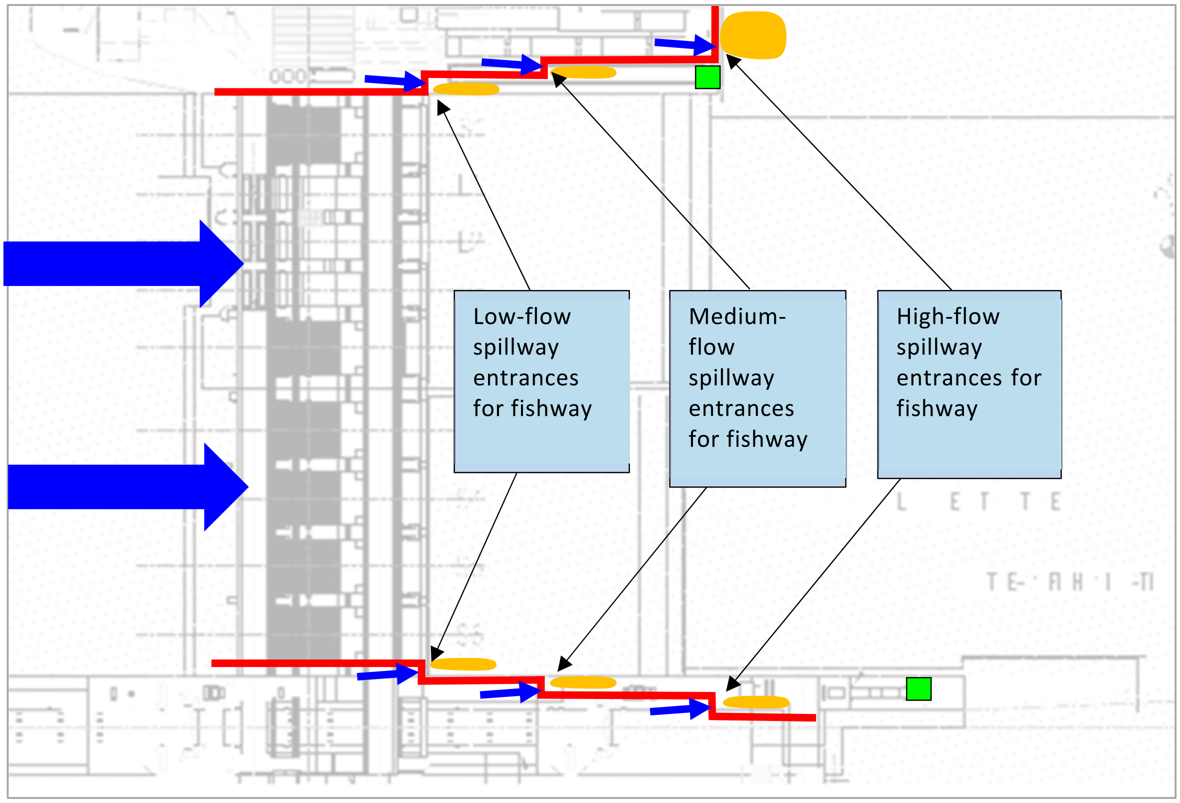

Figure 4-7. Plan view of spillway showing potential abutment shape (red) to enable multiple entrances to accommodate fish attraction zones (orange) at low, medium and high spillway flows. Green squares are fishway entrances proposed by LPHPP.

SUMMARY

Issue: Powerhouse entrances favour surface-dwelling species and are inadequate for benthic species, while the spillway entrances do not accommodate different flow patterns and zones of fish attraction on the spillway. Some species of migrating fish will very likely not locate the proposed fishway entrances and fish passage will be ineffective for those species.

Recommendations: Benthic fishway entrances are needed at the powerhouse, while the thalweg needs to be shaped to guide benthic fish to the fishway. Multiple fishway entrances are required on both sides of the spillway and physical modelling is required to optimise these. The entrance for the fish lock at the navigation lock needs optimisation.

Risk if issue not addressed: Major for benthic species and for species migrating at high flows when the spillway is in use.

Minor for surface/midwater species migrating up to 5,000 m^3/s.

b) Selection of Fish Passage Options

The LPHPP is using dual fish locks on the left abutment and a single fish lock on the right abutment. At the concept level these options may be suitable, but the supplied documentation does not have a comparison with other fishway options, so it is difficult to assess the relative suitability of the selected design.

Fish locks have had variable effectiveness and have been generally inadequate in large tropical rivers. It should be noted that "the locks constructed at the first dams on the Columbia River (Bonneville, The Dalles, McNary) and elsewhere in the USA were abandoned in favour of pool-type fish passes. Similarly, most locks in France are considered to be ineffective (some of them for obvious design reasons), and certain have been replaced by pool fish passes" (Marmulla 2001).

There are three other likely options for the LPHPP that need to be assessed: fish lifts, large bypass channel fishways, or large pool-type (e.g. vertical-slot) fishways. Given the general arrangement of the dam a large bypass channel is unlikely to be suitable as the left-hand abutment does not abut the bank but is joined to the closing dam that continues across the river.

A large pool-type fishway, such as a vertical-slot, with low velocities, low turbulence and large resting pools is a very viable option and needs to be evaluated. Importantly, a pool-type fishway is operating continuously and has no moving parts for maintenance. Fish lifts are widely used at high dams and also needs to be evaluated. They have the advantage of a quick cycle time and overcoming some of the fish behaviour issues of fish locks.

There is a fish lock at the navigation lock which enables fish passage on the right bank. The navigation lock, however, should also be considered for fish passage during construction when there is low headwater and the fish lock would not be operational. The navigation lock may potentially be useful for fish passage at high tailwater levels, by using the overflow section in the abutment.

SUMMARY:

Issue: In the supplied documentation other fishway options have not been considered.

Recommendation: Review other fish passage options using functional criteria. Consider the navigation lock for fish passage during construction.

Risk: Major**.**

c) Fishway Discharge

The LPHPP is designed to comply with MRC Design Guidance, providing 10% of the 95%ile flow and 1 % of the 1-in-1 Year Annual Recurrence Flow. It is likely that the right-hand fish lock, at the navigation lock, may have low attraction, so opportunities to improve attraction flow at this side of the spillway should be utilised during the detailed design stage. It should be noted that any flow that the fishway uses, once the spillway is operational, is not lost hydropower generation.

SUMMARY

Issue: The fishway discharge meets MRC Design Guidance.

Recommendations: No change. Utilise opportunities in detailed design to increase attraction flow of right-hand side fish lock.

Risk if not addressed: Insignificant

d) Water velocity and turbulence

Water velocity criteria meet the MRC Design Guidance. Turbulence is not discussed in the documentation concerning the fish locks or connecting channels and further details are needed. Turbulence is more critical in pool-type fishways; in fish locks, turbulence and water velocity are potentially adjustable.

SUMMARY:

Issue: No information on turbulence.

Recommendations: Provide further data on turbulence.

Risk if not addressed: Minor

e) Fishway Depth

The LPHPP accepts the MRC Design Guidance minimum depth of 3 m. However, the minimum tailwater for the fishway, and the floor levels of the fishway entrances, need to be 1.7 m lower to provide sufficient minimum depth. As flow and tailwater increases, the impact of shallow depth would be reduced.

SUMMARY:

Issue: Water depth is too shallow for large fish and is overestimated in the present design.

Recommendations: Increase design depth to 3 m, and calculate using the lowest operational headwater and tailwater levels.

Risk if not addressed: Minor

f) Lock chamber size and number

The size and number of fish lock chambers are determined by two parameters: migratory biomass and fish behaviour. Migratory biomass is difficult to estimate in large rivers. Generally larger rivers and lowland reaches have larger biomass than smaller rivers and upland reaches. The Xayaburi HPP has used a ARIS acoustic camera to estimate biomass and found up to 5 t of fish passing per hour at certain times, but the ARIS cannot be used at high flows because it is unsafe to sample the Mekong River in highly turbulent flow so this value may be an underestimate if most fish migrate in these higher flow conditions.

Fish behaviour is important because fish locks are cyclic, so that fish need to wait in the lock chamber. Fish will swim in and out of the lock, even with a V-trap. The LPHPP lock chambers are 6 m long by 6 m wide on the left abutment and 6 m long by 4 m wide on the right abutment (navigation lock). The length of these is too short because large fish in the Mekong can be 2 to 3 m long, although the developer indicates the lock chambers are the same dimensions as Xayaburi HPP so consistent in design. Lock chambers of 9 to 12 m need to be evaluated.

In large rivers with potentially high biomass, fish lifts and fish locks have a long entrance channel up to 60 m with a “crowder” (Pavlov 1989; Travade and Larinier 2002). This ensures a high biomass can be collected and large fish will remain in the channel and not exit. On the left abutment the LPHPP fish locks have entrance channels with crowders that are 20 m. Longer entrance channels need to be evaluated. The right hand abutment fish lock appears not to have a crowder, and one should be included.

SUMMARY:

Issue: Lock chambers and entrance channel are too short.

Recommendations: Increase lock chamber and entrance channel length. Add crowder to fish at right abutment

Risk if not addressed: Major

4.3.3 Downstream fish passage

a) Background

The following section is structured by the potential downstream migration paths for fish in the LPHPP, which are through the: reservoir, turbine debris screens, dedicated fish bypass, turbines and spillway (Figure 4-8). For flows up to 5,355 m^3/s, which is the majority of the time, flow passes to the powerhouse, which will guide downstream-migrating fish firstly to the debris screens and turbines. Over 5,355 m^3/s both the powerhouse and spillway are used.

a) Passage through the reservoir

A very common aspect of the life-history of Mekong riverine fish species is to have drifting larvae, which are adapted to flowing water. The larvae typically require a minimum mean channel velocity of 0.3 m/s to be maintained in the drift. In the upper Mekong River this threshold may be higher. In large global rivers with hydropower dams the migratory fish populations with drifting larvae have generally died out upstream. If the water velocity is too low the larvae do not survive. There are several potential reasons for this including: i) the larvae settle in the bottom of the reservoir and die, ii) the larvae starve from lack of suitable planktonic food, iii) the larvae lack access to food, as they are adapted to feeding in flowing water, and iv) larvae are subject to greater predation in the static, less-turbid water of the reservoir.

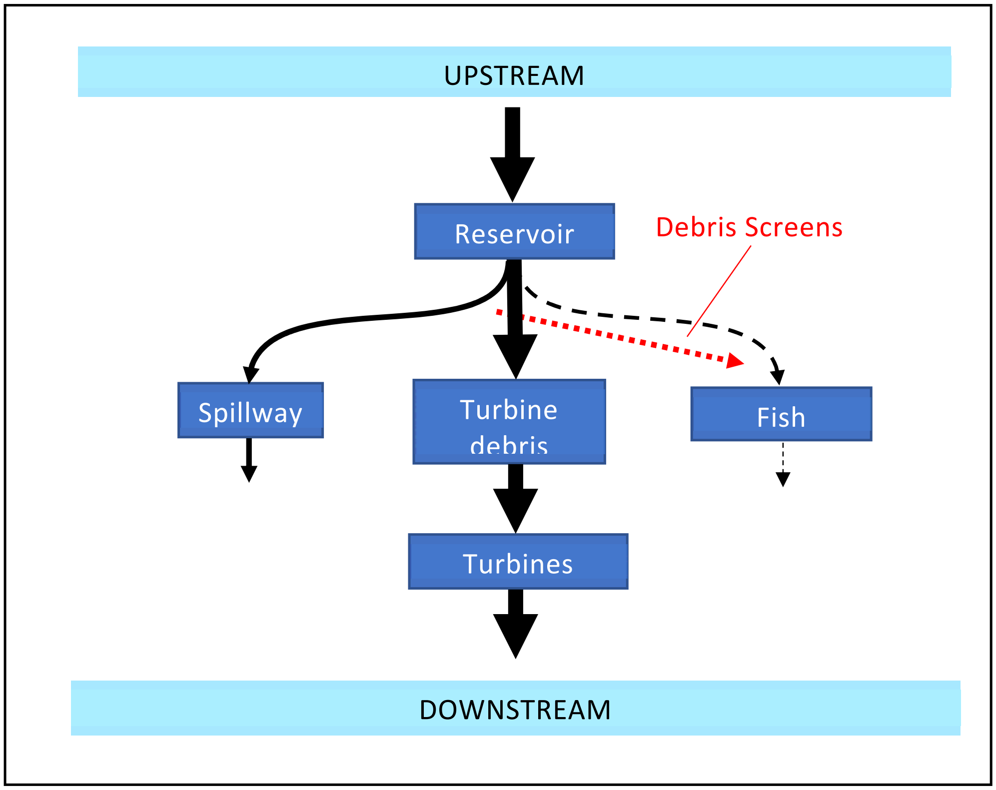

Figure 4-8. Schematic diagram showing the different pathways for downstream-migrating fish, including drifting eggs and larvae. The width of the arrows indicates the frequency and volume of flow.

The reservoir created by the LPHPP is 156 km at low flows. There is insufficient hydraulic data on water velocity to determine the impacts on drifting fish larvae although 2-D concluded that the velocity near the dam ranges between 0.05 m/s with river flow of 1,000 m^3/s to 0.2 m/s with average river flow (about 4,000 m^3/s) to 0.5 m/s with river flow of 10,000 m^3/s, and generally higher further upstream along the reservoir. However the CIA-TBIA report (section 5.4.5) and EIA (section 4.2.6) show that calculated velocities in a section up to 1 km upstream of the dam are less than 0.3 m/s and mostly around 0.2 m/s for 3000 m^3/s, and about 0.3 m/s for 5000 m^3/s. The more recent hydrodynamic model provided in March 2020 for one discharge setting partially addresses this issues, and clearly indicates mean flows through the 40 km upstream of the dam will be below 0.3 m/s required to maintain larval drift. Given the importance of maintaining larval drift, further in-depth modelling at arrange of flows is required because these impacts are likely to be significant, given the length and depth of the reservoir.

Potential impacts on drifting larvae can be mitigated by lowering the reservoir level to maintain water velocity throughout the reservoir; as river discharge increases, the reservoir level can be raised and water velocities can be maintained. It is therefore recommended to review reservoir management with hydraulic modelling to assess the potential to maintain water velocities for larval drift. This may require reservoir water levels to be reduced for periods of time and would impact energy production. This means that a balance between the financial viability of the LPHPP, Internal Rate of Return, Concession Period and Fisheries (and hence ecological and socio-economic) impacts should be found.

SUMMARY

Issue: The reservoir creates a still-water habitat at low flows that can prevent larval drift and causes mortality of this life stage. The discharge that is sufficient to maintain larval drift in the reservoir is unknown.

Recommendations: Conduct further hydraulic modelling. Review reservoir management to mitigate the impact.

Risk if not addressed: Major (until further analysis is done)

b) Passage through the debris screens in front of the turbines

Fish approaching the turbines firstly encounter a debris screen. Detail of the debris screens in the LPHPP are not shown but they are typically vertical bars with gaps of 12 to 20-cm. The gaps allow eggs, larvae, juveniles and adult fish up to approximately 75-cm long to pass through to the turbines. Because of high water velocities at the screens, large fish can be impinged and die; this is a well-known phenomenon at hydropower intakes and cooling water intakes of power stations (Larinier and Travade 2002). Hydraulic modelling of water velocities in front of the screens is needed to assess this risk.

The present screen design is relatively perpendicular to the flow so it does not direct fish to the bypass entrance (**Figure 4-9**). A screen with a more acute angle to the flow is required to direct fish to the bypass (**Figure 4-10**).

Impingement mortality is a very high risk for moderate- to large-sized fish in the LPHPP, which needs to be addressed by developing the screen design.

Preventing impingement of fish in front of turbines and water intakes has led to the development of fish screens with large surface areas, acute angles to the flow, and low water velocities. These designs have been applied widely over the last few decades.

SUMMARY

Issue: In the present design of the LPHPP the debris screen in front of the turbines has an extremely high risk of impingement and mortality of large fish.

Recommendations: The screen needs to be redesigned, with an acute angle and low water velocities

Risk if not addressed: Critical (one of the most critical aspects of the project)

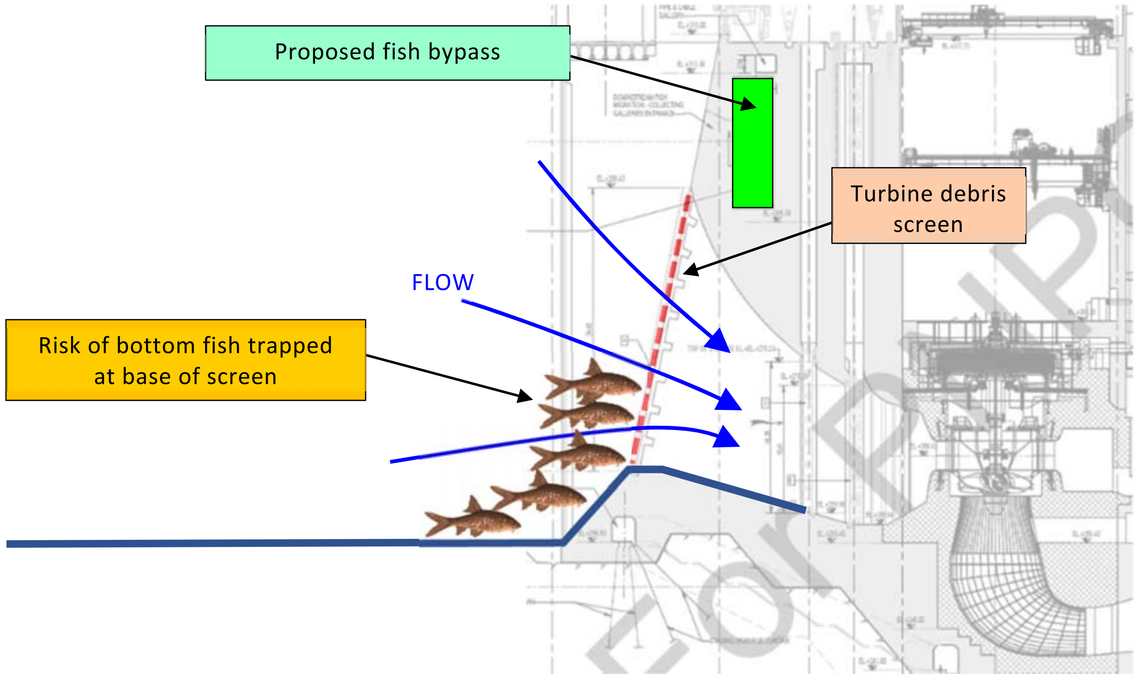

Figure 4-9. Diagram showing proposed debris screen angle, fish bypass entrances, and risk of bottom fish trapped at base of screen.

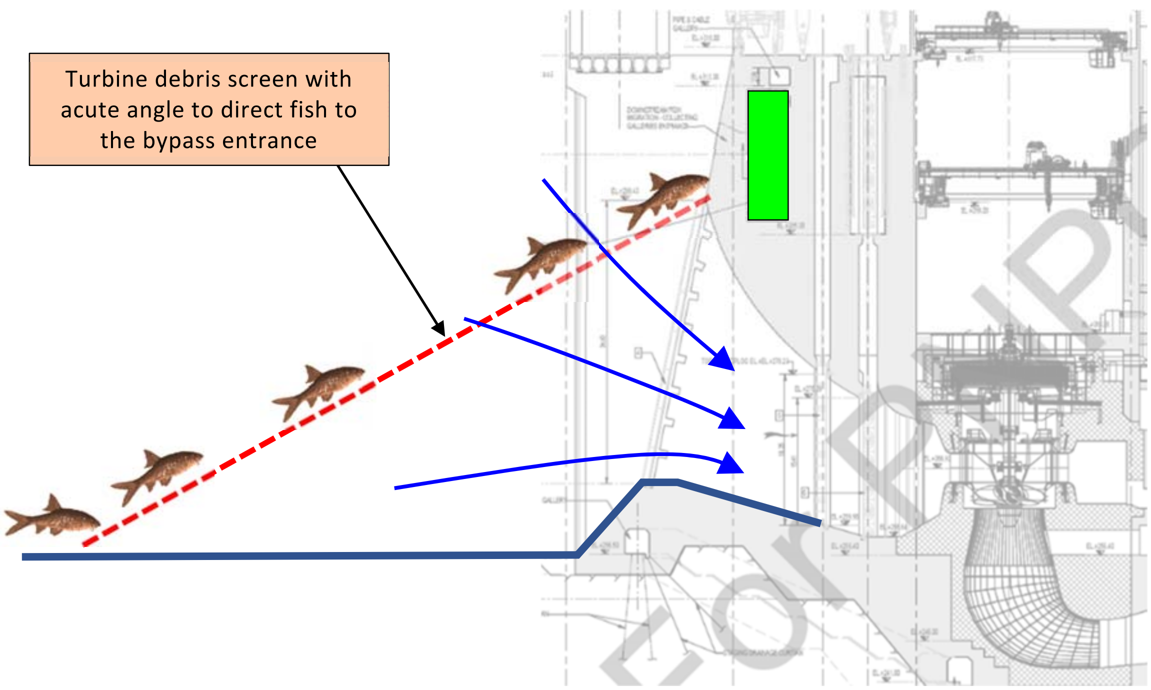

Figure 4-10. Diagram showing proposed debris screen angle, fish bypass entrances, and risk of bottom fish trapped at base of screen.

c) Passage through the dedicated fish bypass

Dedicated fish bypasses have been used successfully elsewhere but they are untested for tropical species. A turbulence of 500 W/m^3 is quoted for the bypass; this may be satisfactory but no data on the impacts on fish are provided. Further information is required.

Summary: In the present design of the LPHPP the fishway provides negligible downstream passage of fish.

d) Passage through the turbines

The LPHPP states it will use "fish friendly" turbines and some of the features stated - such as oil-free hubs, reduced runner blades and rotational speed and minimising gaps - would reduce impact on fish. However, there are no quantitative data on pressure impacts (barotrauma), shear and blade strike. The extent of injuries and mortality from these impacts depends on fish aspects - fish size, swim bladder (gas bladder) morphology and the fragility of the species – and turbine design, including the number of blades (less blades – less injury), blade speed (lower speed - less injury), blade thickness (thicker blades - less injury), number and location of wicket gates (less gates – less injury), and depth of turbine (deeper – less barotrauma).

The physical attributes of the turbines in the LPHPP are described in the documentation but there are no specific data of the impacts of strike, barotrauma and shear on Mekong fishes but some aspects can be extrapolated from other species and are discussed below. There is also no comparison between the three main turbine choices: Alden, Bulb and Kaplan.

Turbine Passage - Blade Strike

Small fish (e.g. <50 mm) will have a low probability of suffering injury from blade strike on the turbines in the LPHPP, but medium to large fish (> 300 mm) have a significant probability of suffering blade strike, which increases with fish size. Hence, it is critical to understand the maximum size of fish that would pass through the debris screens and be exposed to blade strike.

Currently there are no known turbines available globally for dams similar to the height and discharge of LPHPP that protect medium to large fish from blade strike. A thick leading edge on the blade can reduce strike but the only effective mitigation for large fish is to prevent them entering the turbines by specifically-designed fish screens (there are debris screens at present – see above) and diverting them downstream via a dedicated bypass, which the project has proposed.

Turbine Passage - Pressure Impacts (barotrauma)

Some general aspects of barotrauma can also be extrapolated. Those species that have a swim (gas) bladder with a duct connected to the throat (physostomous) are more likely, but not always, to depressurise by releasing gas as they pass through the turbines. This applies to catfish species, which may be less sensitive to this type of injury that other fish. However, species than have a dual swim bladder (cyprinid species) or a closed swim bladder (physoclistous) with no duct, do not readily release gas and have a high probability of suffering injuries and mortality. The extent of these impacts is dependent on the pressure profile through the turbine, which can be determined by computer modelling (Computational Fluid Dynamics [CFD]).

If benthic species with closed or dual swim bladders are acclimated to 20 m depth (300 kPa pressure) upstream, passing through the turbine to the surface of the tailwater (100 kPa) would cause the swim bladder to double in volume – in some cases, protruding from the fish's mouth. If fish are acclimated to surface pressure, there can be less impact. However, turbines develop negative pressure on the downstream side of the blades, which can have high impacts on fish. For example, in a surface-acclimated fish (100kPa) is exposed to 25 kPa negative pressure in a turbine, the swim bladder volume expands four times which causes high mortality. This applies to larvae that have developed a swim bladder, as well as juvenile and adult fish. Therefore, it is critical to understand the pressure profile of the turbine to assess the impact and we request more information. Designing the turbine to have a change in pressure of only 10% (pressure ratio of 0.1) between the lowest pressure (nadir) and the acclimation pressure, would mitigate most impacts from barotrauma. Note that decompression impacts fish, not compression.

Improving the pressure ratio that fish are exposed to can be done: i) guiding all fish to the surface in the forebay so that they are surface-acclimated before passing through the turbines (e.g. with a pressure acclimation weir), and ii) having deep turbines to eliminate sub-atmospheric pressures. The horizontal axis of the turbine blades in the LPHPP are 10 m below the minimum tailwater; this should produce favourable conditions to minimise barotrauma but no CFD modelling is presented.

Shear

Shear is the force generated by two bodies of water moving in different directions, most notably in turbulent flow. Shear can be modelled with CFD and there are some data on the impacts of shear on non-Mekong fish species that would provide an indication of this impact. An initial design criterion for shear is less than 150 cm/s/cm for 99% of flow paths through the turbine. More information on shear from CFD is required to assess the LPHPP turbines.

SUMMARY

Issue: Insufficient information on: size of fish that would pass through debris screens, pressure and shear profiles of turbines, or quantitative assessment of mortality/survival.

Recommendations: Provide information on: size of fish that would pass through debris screens, pressure and shear profiles of turbines (CFD), and quantitative assessment of mortality/survival (CFD). Assess inclusion of a simple pressure acclimation weir in front of the turbines.

Risk if not addressed: Critical

e) Passage through the spillway

The design objective for LPHPP is to provide fish passage from minimum flows to 10,650 m^3/s. The spillway would be used when river flows exceed the powerhouse flows of 5,355 m^3/s, although it could be used at other periods for small discharge to balance flow through the turbines. Larvae, sub-adult and adult fish are likely to be migrating downstream when the spillway is in use, between 5,355 and 10,650 m^3/s.

The spillway uses undershot radial gates, with overshot flap gates to pass debris. Radial gates have a high risk of injuring fish if they partly open, providing undershot flow, which will happen from 5,355m^3/s to 10,650 m^3/s. Injuries occur from pressure changes passing through the gates and shear forces may be involved as well. If the gates are operated fully open there is little risk for fish. The spillway has a relatively smooth profile with no dissipators, so there is no sudden deceleration or direct impacts. It is therefore preferable to operate with fewer gates fully open than more gates partly open.

If the gates are used in the partly open position, which is also likely, it is recommended to either replace the gates with an overshot design, or use the overshot gates within all the radial gates. These small overshot gates can then pass low flows until a radial gate can be fully lifted. The path of fish after they pass through these overshot gates needs to be smooth, not impacted by support beams of the radial gate, with a gradual transition onto the spillway.

The low-level outlet gates are proposed to be used first. These could have significant pressure and shear impacts on fish which need to be investigated.

Gate operation has a significant influence on flow patterns downstream and the effectiveness of fishway entrances. Various configurations of gate operation need to be tested in physical modelling to integrate flow patterns with the spillway entrances for the fishways.

SUMMARY

Issue: Undershot radial gates and the low-level outlet gates can injure fish and cause mortalities.

Recommendations: Replace the gates with an overshot design or utilise overshot gates within all the radial gates. Assess pressure/shear impacts of the low-level outlets and mitigate, if necessary.

Risk if not addressed: Moderate

4.3.4 Fish passage during construction

There are two stages to fish passage during construction: i) when the river is partially blocked by a coffer dam, and the river flows freely on the unblocked side, and ii) when the second coffer dam is installed, which covers the entire river, and flow passes through the completed spillway section. In the documentation supplied these are both not addressed.

In the first stage the cross-section of the river is reduced which would increase water velocity and could impede or block fish passage. Detailed hydrodynamic or physical modelling is required to assess the need to provide fish passage in this stage.

In the second stage, fish cannot pass upstream through the spillway because water velocities are too high, due to the reduction in cross-sectional waterway area, and the laminar nature of the flows. In this stage a dedicated fish passage solution is required. For example, Xayaburi HPP used the navigation lock as an alternative fishway during construction. Alternatively, for the LPHPP a separate fishway could be used.

SUMMARY

Issue: Fish passage during construction has not been addressed adequately.

Recommendations: Do detailed hydrodynamic or physical modelling for the Stage 1 coffer dam and provide a dedicated fish passage solution for Stage 2, and Stage 1 if required. Investigate using the navigation lock for fish passage.

Risk if not addressed: Moderate

4.3.5 Summary of Key Recommendations

Key recommendations are summarised in Table 4-2

Table 4-2. Key Recommendations for Fish Passage.

Upstream Passage

- Assess minimum design flow; if needed, lower tailwater level and floor levels of fishways to match.
- If a lower operating level is selected, lower the levels of the fishways accordingly
- Add benthic fishway entrances and shape thalweg to guide migratory fish.
- Add spillway entrances for fishways, and optimise in physical modelling.
- Review fishway design options comprehensively.
- If fish lock design is pursued, increase lock chamber length and entrance chamber length.

Downstream Passage

- Assess larval drift at various flows with hydraulic modelling and review reservoir management, if necessary.
- Change debris screen design to have a more acute angle to guide fish to the bypass; and design screen to ensure there are low water velocities to prevent impingement.
- Investigate a simple pressure acclimation weir in front of the turbines.

- Provide data on blade strike, shear and pressure of the turbines; and the size of fish passing through the debris screens.
- Spillway: Use radial gates fully open to reduce impacts on fish, or replace radial gate with an overshot design, or use overshot gates within all the radial gates. Ensure design of radial gates and spillway has a smooth path for fish.

Passage during Construction

- Do detailed hydrodynamic or physical modelling for the Stage 1 coffer dam and provide a dedicated fish passage solution for Stage 2, and Stage 1 if required.
- Investigate using the navigation lock for fish passage.

4.4 Risk assessment of LPHPP Fish Passage

4.4.1 Background

Risk assessment is a qualitative analysis of the consequence or scale of risk and the likelihood or probability of the risk occurring (Table 4-3). These two values are combined to produce an overall risk score (Table 4-4). A risk management framework operates by establishing the context (i.e. proposed hydropower development); identifying the risks on the existing situation (consequences and likelihood); assessing the risks; and treating the risks. Consequently, it is a useful tool to prioritise actions and resources, and to identify knowledge gaps, which then inform the monitoring programme.

Table 4-3. Consequence and Likelihood scores.

Consequence	Likelihood
Critical	Almost certain
Major	Likely
Moderate	Possible
Minor	Unlikely
Insignificant	Rare

Table 4-4. Risk matrix.

Key: Low | Moderate | High | Very High

		Consequence				
		Insignificant	Minor	Moderate	Major	Critical
Likelihood	Very likely	M	M	H	VH	VH
	Likely	M	M	H	H	VH
	Possible	L	M	M	H	VH
	Unlikely	L	L	M	M	H
	Rare	L	L	M	M	H

A measure of risk is typically derived by multiplying *likelihood* by *consequence*. The ratings refer to the probability (likelihood) of the impact (consequence) occurring if a scheme is proposed based on attributes about the ecology of the fish and other aquatic species and the riverine environment in which the development is being proposed. The consequence refers to the scale of the potential impact based on knowledge of ecological impact of the scheme from previous similar schemes. The ratings are, where possible, based on scientific evidence otherwise expert judgment is used, but this carries a higher degree of uncertainty in the assessment procedure that must be accounted for. Where possible, information should be drawn from approved documentation or case studies of existing schemes. Where knowledge is deficient or uncertainty high, the precautionary principle should come into force to prevent unforeseen impacts.

In the present risk analysis the following risks are assessed: i) the Proposed Design (Table 4-5) and ii) the Proposed Design after applying recommendations and mitigations from the present report (Table 4-6); the latter assesses the *probability that the risk can be mitigated*, which not only reflects the recommendations but also assumes ongoing discussion between the developer and the MRC, which the JC may wish to propose as conditions, that would result in the optimal design being presented.

In these two risk assessments only the most important risks have been examined so that the *consequence* of these is either *major* or *extreme* and hence, the risk scores, based on differing likelihoods are *Moderate*, *High* or *Very High*. The risk assessment of the Proposed Design reflects the issues raised in this review, but importantly it prioritizes where the design needs to be improved. Those risks that are *Very High* or *High* are the highest priorities to address in the design.

The risks can be viewed as links in a chain for upstream and downstream migration – attraction into, passage through, and exit of a fishway – that are all essential to complete fish passage. Hence, all risks in a horizontal block within the table need to be addressed to enable the full migration of that group to be completed. Other ecological links to complete life cycles are also essential, such as access to spawning and refuge areas, and these are addressed elsewhere in this report.

4.4.2 Discussion

The risk assessment of the proposed fish passage facilities highlights that for upstream passage large and benthic fish are disadvantaged in the present design, and the design is more effective at low flows than at higher flows. Downstream passage has greater risks overall, again with larger and benthic fish more disadvantaged.

Applying all the recommendations reduces most of the risks but leaves two that are *very high*, which are: i) maintaining drift of larvae through the impoundment and ii) passing large-bodied fish downstream the dam, particularly at the debris screens. These two risks can be mitigated in theory, but both would potentially require a major change in the scope of the LPHPP, and an innovative approach to hydropower and fish passage. If these

Table 4-5. Risk Assessment of Proposed Design based on criteria in Table 3, for each size class, behaviour category, migration flow and biomass.

	Upstream Migration			Downstream Migration			
	Limited attraction and entry into fish passage facilities	Limited ascent of fishway	Ineffective exit – risk of fallback	Limited passage through impoundment	Limited attraction and entry into fish passage facilities	Mortality passing Luang Prabang site – including spillway and turbines	Inadequate exit; risk of predation downstream
Life Stage							
Larvae & fry	N/A	N/A	N/A	Very High	Very High	Moderate	Moderate
Small-bodied species (5 -30 cm)	High	Low	Low	Moderate	Very High	High	Moderate
Medium-bodied (30-150 cm)	Very High	High	Low	Low	Very High	High	Moderate
Large-bodied (150-300 cm)	Very High	Very high	Low	Low	Very High	Very High	Low
Behaviour							
Surface	Low	Low	Low	Low	Very High	High	Moderate
Mid-water	Moderate	Low	Low	Low	Very High	Very High	Moderate
Benthic (including thalweg)	Very High	High	Low	Low	Very High	Very High	Moderate
Migration Flow							
Low (dry season)	Moderate	Moderate	Low	Very High	Very High	Very High	Moderate
Moderate (early wet, late wet)	High	Moderate	Low	Moderate	High	High	Moderate
High (wet season)	Very High	High	Low	Low	Low	Low	Low
High Biomass	High	High	Low	Low	Very High	Very High	High

Table 4-6. Reassessment of risk of Proposed Design after applying recommendations and mitigations outlined in the present report.

	Upstream Migration			Downstream Migration			
	Limited attraction and entry into fish passage facilities	Limited ascent of fishway	Ineffective exit – risk of fallback	Limited passage through impoundment	Limited attraction and entry into fish passage facilities	Mortality passing Luang Prabang site – including dam turbines	Inadequate exit; risk of predation downstream
Life Stage							
Larvae & fry	N/A	N/A	N/A	Very high	Moderate	Moderate	Moderate
Small-bodied species (5 -30 cm)	Moderate	Moderate	Low	Low	Moderate	Moderate	Low
Medium-bodied (30-150 cm)	Moderate	Moderate	Low	Low	Moderate	High	Low
Large-bodied (150-300 cm)	High	High	Low	Low	Moderate	Very high	Low
Behaviour							
Surface	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Mid-water	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Benthic (including thalweg)	High	Moderate	Low	Low	Moderate	High	Moderate
Migration Flow							
Low (dry season)	Low	Low	Low	High	Moderate	High	Moderate
Moderate (early wet, late wet)	Moderate	Low	Low	Low	Moderate	Moderate	Low
High (wet season)	High	Low	Low	Low	Low	Low	Low
High Biomass	High	High	Low	Low	Moderate	Moderate	Moderate

risks eventuate, they would severely impact the sustainability of the species impacted, affecting populations upstream and transboundary downstream.

4.7 Conclusion

The LPHPP developer has done extensive design work on fish passage but it is still in a preliminary stage with insufficient information to make a complete assessment. Based on the available information, numerous recommendations have been made. These would reduce many of the major risks of the design. However, significant risks remain regarding downstream fish passage, especially concerning larval drift in the reservoir and the fate of large-bodied fish at the debris screens in front of the turbines. Addressing the former may reduce the total power output of the LPHPP, while the latter would require innovative approaches to fish passage and hydropower design.

5. IMPLICATIONS OF MULTIPLE DAMS AND TRANSBOUNDARY EFFECTS

5.1 Impacts of multiple reservoirs

Whilst the PNPCA procedure is explicitly targeted towards review of individual HPP schemes, placing this in the context of the other tributary and mainstream dams is central to any determination of whether it is a reasonable and equitable use of the water resources of the LMB. For the LPHPP prior consultation, it is particularly important to consider the cumulative impacts of the upper cascade of dams in Lao PDR, especially to include Xayaburi that is currently being commissioned and Pak Lay and Pak Beng HPPs, which have already undergone prior consultation. In addition, Sanakham HPP should be included given it is likely to be submitted for Prior Consultation in the near future. These will likely have additive impacts on fish and fisheries because the reach between Sanakham tailwater and the headwaters of the Pak Beng impoundment will essentially be converted to a series of reservoirs, if Sanakham, Pak Lay, Pak Beng HPPs are developed in addition to Xayaburi HPP and LPHPP.

In determining the cumulative impact, it is important to understand the relationship between the various dams in the cascade as well as those in the tributaries (Figure 5-1).

The Upper Lao cascade reach has a total length of 732 km with a drop in altitude from 342 m asl to 166 m asl, i.e. a fall of 176 m. Thus, the average slope on this reach is 0.24 m/km, which is gentle, but steeper (around double) than downstream from Vientiane.

Table 5-1 gives an overview on the planned dam locations within the Upper Lao Cascade reach. Information on the planned reservoirs from ISH306 (MRC 2016a) indicate they have lengths ranging from around 60 km to over 100 km (Table 5-1). This suggests that around two-thirds of the distance between Sanakham and the upstream headwater of Pak Beng will be reservoirs and one-third free-flowing river sections. However, these figures seem to be an approximation when compared with information on reservoir length collated from the TRRs for Pak Lay, Xayaburi, Luang Prabang and Pak Beng (http://www.mrcmekong.org/topics/pnpca-prior-consultation/). This partly arises because of changes in design specification, e.g. Laung Prabang has changed its design height from 310 to 312 m asl, which will mean the headwaters of the LPHPP reservoir will merge with the tailwaters of Pak Beng, i.e. there will be no free flowing river. Similarly, Xayaburi HPP has a modified design of 275 m, which means the 25-km free-flowing section downstream of LPHPP is likely inundate in all but low flow conditions, although the developers now indicate that new modelling, that as yet has not been made available, may maintain some or all of this free flowing reach. Notwithstanding, the free-flowing reach may be compromised because the section will be starved of sediment and become incised with bedrock substrate, lacking coarse sediment substrate. (See Annex D).

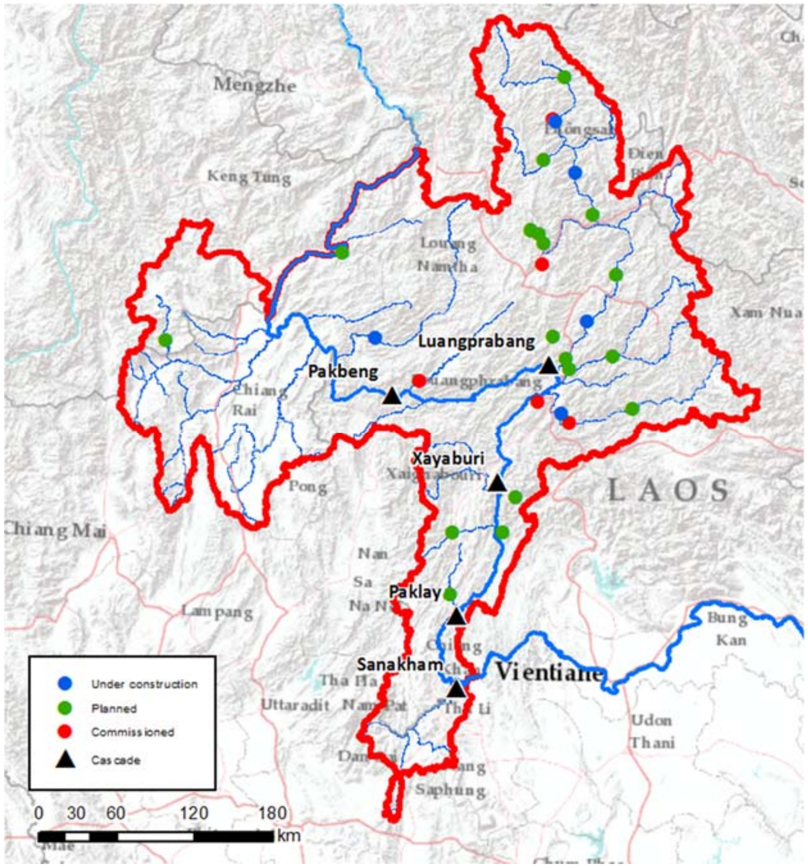

Figure 5-1. LMB catchment upstream of Sanakham including the Lao mainstream cascade as well as tributary dams commissioned, under construction and planned for the BDP 2030 scenario (source ISH 306; MRC 2016a)

In reality, it is likely the majority of the length of this reach covered by the upper Lao cascade will be transformed from a free-flowing river to a series of impoundments, with consequent changes in hydraulic conditions and intermittent barriers. This can be visualized in a longitudinal profile of the upper Lao cascade (Figure 5-2). Critically the figure shows the only significant length of free-flowing river will be between the headwaters of Xayaburi HPP reservoir and LPHPP, but the current status of the river suggests this is eliminated by the present operational regime. In addition, the reach between the headwaters of Luang Prabang HPP reservoir and the tailwaters of Pak Beng HPP will also be effectively eliminated by the change in design height.

Table 5-1. Length of reservoirs and river reaches in the Lao Cascade - information based on ISH306 and interpretation of MRC TRRs.

Reach from:	Reach to:	Cumulative distance from u/s boundary km	Reach length km	Reservoir length km	River reach raining according to ISH 306 km	Zone of influence of impoundment highlighted in TRRs
Model Boundary	**Pak Beng**	0	127	73	54	97 km to Keng Pha Dai considered the upper zone of influence[2]
Pak Beng	**Luang Prabang**	127	143	100	43	156 km in LPHPP documents
Luang Prabang	**Xayaburi**	270	129.5	80	49.5	100 in TRR
Xayaburi	**Pak Lay**	399.5	121.5	80	41.5	109 km in TRR
Pak Lay	**Sanakham**	521	81	58	23	
Sanakham	Model Boundary	602	130			

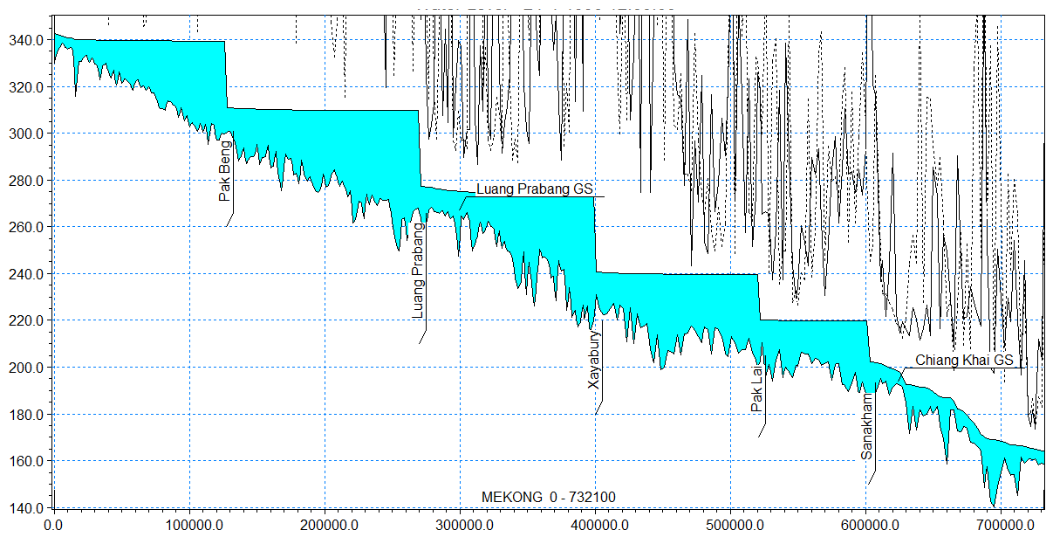

Figure 5-2. Longitudinal profile of the upper Lao cascade of HPPs. The lower outline of the blue polygon illustrates the thalweg in the Mekong (i.e. the lowest elevation in each cross-section), which shows the distribution of deep pools, while the upper outline of the blue polygon illustrates the water surface after construction of all five dams (Source: ISH 306).

[2] The Pak Beng developer has been requested to lower the operating level to avoid inundation of the Keng Pha Dai reef

This cascade will change the whole dynamics of the upper Mekong ecological zone in Lao PDR. It will inundate riverine habitat and flood spawning and nursery habitats of fish, alter the food web and ecosystem functioning, and potentially result in loss of fisheries and OAAs on which many of the rural people depend. It is also important to consider the cumulative impacts because Luang Prabang is immediately upstream of Xayaburi, which has recently become operational and will likely regulate movement of fish in an upstream direction depending on the efficacy of the fish passage facilities. Currently this is unknown and requires considerable investment to evaluate the efficiency of the fish pass to pass the diversity and biomass of fish required to maintain stock status.

If considering just Xayaburi HPP and LPHPP, approximately 250 km of river will transition from riverine habitat to impounded water, i.e. lotic habitat. This will result in loss of the riverine habitat utilised by rhithron species, loss of spawning (and some nursery) habitat used by migratory fish (white and grey fishes), exposure of the fish community to the proliferation of generalist (eurytopic) and non-native species, and potential loss of the deep pool refuge areas typically used by fish in the dry season, although the LPHPP worryingly suggests the impoundment will provide more deep water areas. This whole scenario will undoubtedly lead to disruption of the fish communities and loss of numerous species that will be unable to adapt to the new environment. Iconic species such as the Mekong giant catfish and other mega fishes will likely be lost from the region, but critically long-distance and short range migratory whitefish species will be adversely affected, largely because they cannot breed in the new environment.

In addition to the change in habitat, the two dams act as major barriers to migration. Dams disrupt longitudinal connectivity by acting as barriers to movement, which can potentially be mitigated through provision of suitable fish passage facilities. However, fish passes are rarely, if ever, 100% efficient, especially for passing the highly diverse fish species fauna found in tropical rivers. Although fish passage facilities are provided at Xayaburi HPP and proposed at LPHPP, they have not been proven to pass the high volumes of fish (5 tonnes per hour has been recorded at Xayaburi) and species diversity that must move up and downstream to maintain their life cycles. If these two dams are added to the other three dams in the upper Lao cascade, the situation will become progressively worse. The cumulative effects of reducing migration success at each dam will not be additive but the product of success at each facility. In addition, the probability of bypassing several dams in series decreases with each successive dam, irrespective of the efficiency of each dam.

If fish are able to bypass the dam infrastructure they are also subjected to further hydraulic barriers because fish are not adapted to passing upstream through extensive impounded reaches and will likely lose their flow-related migratory stimuli and get lost in the impoundment. This is exacerbated by the potential loss of flow to facilitate downstream drift of larvae. Although the developers indicated flows through the reservoir will be above the 0.3 m/s threshold for downstream drift of larvae, this is only the case closer to the dam and 2-D modelling of the whole impoundment suggests flows in the 40 km of reservoir upstream of the dam will be insufficient to maintain larval drift. Further hydraulic modelling of the flows through the reservoir at a range of flows are required is required to confirm if these flow dynamics persist through the impoundment, and are maintained at all times and operation regimes.

Finally, should adults be able to successfully pass upstream and breed, they and their larval offspring must pass downstream to nursery and feeding habitats, potentially 1,000s of kilometres downstream. If they are able to bypass the reservoir (note adults also use flow cues for downstream migration) they will have to negotiate the dam infrastructure at each site and as discussed above may suffer considerable damage and mortality passing through turbines and through undershot gates. The level of mortality is potentially high, irrespective of the assertion that the turbines are 'fish friendly', and mortality is likely 100% for larval stages because of the high pressures experienced in the turbines. Similar high mortalities are also likely to occur if the larvae pass through the spillway. Consequently, the cumulative mortality rates past successive dams are likely to be considerable, to the detriment of fish recruitment and production, and ultimately catches.

Assuming, for illustration purposes, that all the fishpass facilities have the same efficiency; if 80% of the fish arriving at the dam structure can successfully pass upstream (or downstream), then only 33% of the total fish would make it through all 5 dam fishpasses, conversely if the efficiency is only 30%, then virtually no fish would make it past the final structure (Table 5.2).

These major disruptions to the habitat and connectivity in the river system could have serious implications on the fish catches from the region, as the major species caught are rhithron (G1) and whitefish species (G2 & G3) (see Table 5-3). Whilst they may be replaced by generalist (G6) and non-native species, these latter species are lower value and evidence from elsewhere suggests the productivity of reservoirs is significantly lower than the natural river system (as low as 30% of the biomass found in the unmodified river system). This is likely to be the case for the reservoirs in the upper cascade because they are run-

Table 5-2. An illustration of the multiplicative effect of successive fishpass structures in a cascade, each with the same efficiency in passing fish.

	HPP Fishpass infrastructure				
Efficiency	**1**	**2**	**3**	**4**	**5**
80%	80%	64%	51%	41%	33%
70%	70%	49%	34%	24%	17%
60%	60%	36%	22%	13%	8%
50%	50%	25%	13%	6%	3%
40%	40%	16%	6%	3%	1%
30%	30%	9%	3%	1%	0%

of-river with short retention time of water (3-9 days), so there is little opportunity for primary productivity to build up in the reservoir to support secondary and fish productivity. These scenarios are modelled by the MRC Council Study (MRC 2017) and predict a significant decline in fish production and diversity in the region.

Table 5-3. Percentage contribution of each fish guild / indicator to the overall catch in each zone (based on Council study BioRA Final Technical Report, Appendix G [MRC 2016b]; grey cells highlight dominant guilds)

BioRa Zones		1	2	3	4	5	6	7	8
Council study	LPHPP	Upper cascade		Middle section	Lower cascade		Tonle Sap (river & lake)		Delta
Rhithron resident		13.25	16.09	8.85	11.56	0.20	9.39	5.43	0.04
Main channel resident (long distance white)	Migratory white fish	1.81	26.22	43.06	5.20	2.68	8.19	5.71	0.04
Main channel spawner (short distance white)	Migratory white fish	56.88	43.16	37.90	37.81	15.64	28.42	23.09	39.15
Floodplain spawner (grey)	Grey fish	1.74	0.00	2.28	13.03	15.57	22.46	18.56	4.32
Floodplain resident (black)	Black fish	3.70	5.68	1.63	10.93	63.60	22.49	20.16	13.12
Eurytopic (generalist)	Grey fish	0.07	0.00	0.05	5.81	0.21	6.68	16.96	10.27
Estuarine resident	Others	0.00	0.55	1.24	4.37	0.46	0.62	4.83	14.98
Anadromous	Others	0.00	0.00	0.45	0.88	0.01		0.24	0.80
Catadromous	Others				0.17			0.04	0.03
Marine visitor	Others	0.00	0.00	0.00	2.73	0.77	0.18	1.59	2.10
Non-native	Non-native	22.54	8.30	4.53	7.53	0.88	1.56	3.39	13.06

As indicated, the overall impact of the upper Lao PDR cascade of dams is modification of the riverine ecosystem into a series of lacustrine water bodies. Evidence from elsewhere in the world where cascades of dams are built (e.g. Winemiller et al. 2017) shows the flooding of spawning and nursery habitats will result in the collapse of the traditional riverine stocks and fisheries. The fish community structure will inevitably change and productivity almost always declines, changing from large valuable riverine species to small still water species or a proliferation of alien invasive species such as common carp or tilapia. The problem faced in the upper Lao PDR cascade is that the impoundments created upstream of each dam flood back to the next upstream dam leaving little free-flowing riverine habitat in which fish that bypass the dam can spawn and reproduce. Consequently, the remaining habitat is not conducive to natural fish production so there is the likelihood that yield from the modified river will be heavily compromised and cannot be compensated by stocking or aquaculture. This problem is further exacerbated because access to the tributary rivers is impeded by the construction of many tributary dams without any fish passage facilities. These dams are usually near the confluence with the mainstem of the Mekong (see Figure 5-1) or flow dynamics in the mainstem reservoirs prevent migrating fish from finding the mouth of the tributary.

The cumulative impacts from all HPP developments will be substantial and will need careful management at the basin scale. In this context, it is critical that the developer explores, in collaboration with the MRC and riparian country agencies, the contribution of LPHPP to the impact of multiple dams on the hydrology and ecosystem functioning, with particular attention to the additional impact due to the Luang Prabang HPP on the altered ecosystems. Integration with the Pak Beng and Xayaburi HPPs is critical given that the former will be affected by the LPHPP backwater and will in turn be affected by the Pak Beng HPP tailwater, and the latter, Xayaburi HPP, which is now operational and backs up to the dam wall of LPHPP. Importantly lessons could be learnt from the initial operations at Xayaburi that may be relevant to the final design of the LPHPP. Consequently, cumulative impacts of multiple dams on aquatic communities and fisheries, and the people that depend on them, need to be more clearly addressed. The basin development scenarios envisioned in the MRC Council Study (MRC 2017c) should be consulted in this regard. This will highlight the implications of the impacts at both the local and basin-wide scales, so the relevance of the proposed developments is reflected for all riparian countries.

It should be recognised that considerable data are held by the MRC and MCs to understand the impact of HPP developments on the fish and aquatic habitats and their importance to delivering ecosystem services, including fisheries, in the LMB. This is essentially the outputs of the Council Study and the developers and MCs should work with MRC to make use of this tool. The developers and MCs should also make better use of MRC data and capacity to develop simpler informative models prior to the PNPCA to ensure robust information on the baseline status and likely impact of the dam is provided. Use of the MRC Council Study DRIFT model will support this requirement.

5.2 Transboundary fisheries impacts

As previously indicated, assessment of transboundary impacts are largely restricted to descriptions of the fisheries in the LMB and the conclusion that "The upper migration system appears to be relatively isolated, with little exchange to the further downstream migration systems" (CIA-TBIA Section 5.5.3). The CIA-TBIA also recognises the cumulative impact of the upper Lao cascade but incorrectly interprets that "… fishes mainly migrate into areas further upstream of Pak Beng for spawning" " (CIA-TBIA Section 5.5.3).

This emphasis on connectivity with the stretch upstream of Pak Beng is of concern, partly because there is insufficient free-flowing river up to the first Chinese dam to support the whole of the fishery in the upper migration zone, and it seems to neglect the key links to downstream fisheries zones and the contribution made to fisheries through exchange between the upper and middle and lower migration zones (Figure 3-2). This is emphasised in the conclusion on transboundary impacts "It is therefore expected that the transboundary impact concerning the fish migration is mainly affecting the upper migration system with migration towards China and can hardly be measured in the south towards Thailand, Cambodia and Vietnam" (CIA-TBIA Section 6.2).

This conclusion largely ignores the substantial knowledge about the exchange between zones (Poulsen 2004; Baran 2006, Cowx et al. 2015; MRC 2017a, b), not least from larval drift studies and studies on fish migration patterns beyond Poulsen (2002a). For example, Cowx et al. (2015) concluded that larvae caught in the middle and lower floodplain systems of Laos probably originated in upper Laos, perhaps 1000 km upstream and Hogan et al. (2007) confirmed that *Pangasius kempfri* is anadromous based on otolith chemistry, therefore moving between the ocean and northern Laos. Similarly, iconic species such as the Mekong giant catfish and the threatened Mekong stingray, and *Probarbus julllieni* are known to move between zones.

This rather superficial reflection on the exchange of fish between the zones needs reconsideration and a more robust transboundary study carried out. This should include an assessment of fish species diversity and abundance or catch composition with special emphasis on migratory main channel resident guilds and migratory main channel spawning guilds (PDG2009 para. 57). This transboundary fisheries impact assessment should include impacts both upstream in Lao PDR and Thailand and downstream in Lao PDR, Thailand, Cambodia and Viet Nam (the same applies for social impacts and economic impacts). The overall economic value of these transboundary migratory fish species needs to be assessed. Transboundary impacts such as lost income generation, livelihoods, food security and nutritional security, as well as replacement costs from loss of fisheries, should be assessed for the "no mitigation" scenario to understand the magnitude of the risks. In addition, such a study should also consider the impacts of sediment depletion from LPHPP and the upper cascade on river morphology and delivery of nutrients to the lower river system. The latter is partly addressed in the water quality impacts (See Annex E), but determination of the impact on fisheries productivity in the lower Mekong should be included.

6. FISHERIES MONITORING, MITIGATION AND COMPENSATION MEASURES

6.1 Monitoring programme proposed by the EIA

The LPHPP documentation provides a reasonable review of the fisheries and aquatic resources in the LPHPP area, based on MRC reports, data gathered during prior consultations for Xayaburi and Pak Beng and as part of the concession agreement during the development of Xayaburi HPP. Unfortunately little data were collected during the pre-assessment period for LPHPP; information being restricted to sampling five sites on four occasions in February, June, September and November 2019 with an unknown gear, ARIS image analysis of numbers of fish moving passed a fixed location, and limited, undefined, market surveys. The developer has indicated further data are being collected but these have not been provided and given some additional data were provided in March 2020 it is unclear why these data were not comprehensive coverage at least until the end of 2019 and thus provide a more robust overview of the sampling programme. Further, no indication is given of the sampling methods used or replication. The outputs from the pre-assessment are largely inventories of species caught, categorization of their guild into white, grey and black fishes, and some numerical data on number of each species caught at each site during the several sampling events, plus some ARIS coverage of numbers of fish moving. Such limited sampling prevents an understanding of temporal or spatial variability in the catches and thus the impact of LPHPP on environmental change.

The LPHPP EMPP (Section 7.2) recommends that monitoring should include "…5 stations in [the] reservoir and Mekong River and [a] monitoring station at the fish passing facility". The recommended frequency of sampling is 4 times per year (every 3 months), and the method is "Fish Species Identification by classification guidance books …". This information provides nothing on the sampling method or how abundance and biomass, species composition, migratory and reproductive parameters are collected or how the information is linked to environmental change and therefore how impact assessment is carried out.

Given these weaknesses of fisheries assessment, it is recommended that a comprehensive monitoring programme is designed and implemented to establish the true baseline status of the fisheries and OAAs before construction starts and carry the programme through the construction and operational phases. This should follow the procedures described in the JEM Programme (MRC 2019c), and include sourcing data on the efficacy of the fish pass at Xayaburi during the final design and construction phases, and then including monitoring the Luang Prabang fishpass during the operational phase. The same programmes should be maintained throughout the construction and operational phases, although additional activities will be required during the construction phase. The programme should establish clear objectives and establish sampling protocols to evaluate specific indicators of the status and trends in the fisheries and link them to dam operation.

Monitoring activities should include, but not be restricted to the following (from PDG 2019 Clause 192, MRC 2019d):

i. The season of movement upstream and any hydrological triggers of migration (e.g. onset of flooding cycle) for the main species.

ii. 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).

iii. 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.

iv. The distance (spatial scale) of cyclic migrations of each guild.

v. 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.

vi. 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.

The monitoring protocol needs to be targeted at individual fish species as well as community structure and ecological networks, and account for daily and seasonal variability in ecological characteristics related to hydrological conditions. There is also a need to establish a system to flag any adverse changes in fish species population and community dynamics. This is particularly important because of the large number of threatened species inhabiting the impact area of the LPHPP. Such a programme requires a realistic and properly costed monitoring programme that should build on existing MRC and larval drift surveys, fisher catch monitoring, household surveys and market studies (see below). The costs of all monitoring should be borne by the developer and the sampling protocol and programme of activities should be approved through independent evaluation, and by line agencies from all Mekong riparian countries and the MRC as advised in the PDG.

Two further aspects that need dedicated monitoring protocols are: i) studies to improve understanding of fish migration up and downstream past the HPP infrastructure, including through the upstream impoundment, and ii) studies on the socio-economic, livelihoods and food security perspectives associated with the dam development. The migration studies will need to include tagging and tracking studies using bespoke equipment to test the efficiency of the fish passage facilities and any damage cause to fish passing downstream. The socio-economic studies will require household and market surveys and regular rapid rural appraisal studies to determine dependence on the fisheries and contribution that fisheries make to livelihoods and food security.

6.2 Proposed fisheries management and mitigation measures

The EIA (Vol 4-1, Section 5.3.4) separates the potential impact on fisheries and proposals for mitigation measures for the construction and operational phases of the scheme.

The main impact considered during the construction phase relates to narrowing of the channel by coffer dams increasing water velocity both up and downstream. They suggest that some species may not be able to cope with the "….. increasing velocity due to the decrease of channel width "and " the fast flowing water could transport egg and larvae to an unsuitable habitat." This is a rather speculative statement and unlikely given the dam infrastructure is usually built in stages and the main periods of migration both up and downstream are not during the peak flooding season when this scenario is likely to occur. The statement also fails to acknowledge the dam will be closed at some stage of construction and alternative fish passage facilities will be required. Note: Xayaburi HPP made use of the navigation lock during this period.

During the field visit on 4 December 2019, the developers indicated that the majority of construction will be done within a retaining wall on the right-hand bank and the river will only be blocked when the closure structure on the left-hand bank is finally built. The duration of complete closure is unknown but alternative migration pathways needed to integrated into the design should passage be considered essential.

The LPHPP EIA suggests that "there are no direct mitigation measures to cope with fish migration during the construction and the best solution is management of the fish resources and habitats both up and downstream of the scheme". They also suggest strict enforcement of fishing gear regulations and methods. This proposal gives no consideration of the direct impact of the dam construction activities on fish population dynamics and is not addressing the issue. Restricting fishing around the dam area will have considerable implications for local people dependent on the fisheries for income and food security, and no compensatory measures are proposed. The comment about regulating illegal fishing activities is deflecting from the main issue, and is a statutory fisheries management action. It is possible that workers at the dam may use these illegal methods to catch fish and this should be managed by the operators as part of their concession agreement.

During the operational phase, the presence of the dam infrastructure impeding fish migration was highlighted in the main EIA on fisheries. This is based on the premise that migratory whitefish are the most common species present in the region of the dam, and in particular small white fishes complete their life cycle in one calendar year. The EIA also states "not all fish species caught in the project area are threatened by the mainstream dam. Some species have limited migrations over short ranges have only limited migrations over short ranges … whilst other species are highly adaptable to habitat modifications including an impoundment area". This assumption is of concern because data compiled during the MRC Council Study do not support this assertion; most species have life cycles of more than one year. Also, as previously stated, many of the species found in the region belong to the Rhithron Guild and are thus resident in the area, and dependent on flowing water habitats.

The EIA further discusses the triggers to migration, calling upon the work of Baran (2006) based on migration studies around the Khone Falls. They used Baran's review of 768 species from the Mekong to argue that migration of only 10% of species was triggered by river discharge, thus few species would be affected by flow alteration at LPHPP, which is a run-of-river scheme. Note 80% of species were considered to be triggered by change in water level. This is a very biased assessment and the analysis should have been run on species recorded by their own or MRC studies in the region: a very different local scenario may be established.

The EIA also acknowledges that the LPHPP has a backwater effect of ≈157 km, and probably greater if the operating level of 275 m asl is valid, and there will be a shift in species composition. This is highly likely and limnophilic (still water) species will dominate, but invasive species, such as common carp and Nile tilapia, will likely benefit most from the change in habitat.

Finally, the EIA also acknowledges the impoundment will cause a change in flow dynamics and reduce current velocity, thus potentially having an effect on downstream drifting larvae. There is a discussion, based exclusively on European studies because there are considered few studies on drifting larvae in the Mekong (but see Cowx et al. 2015 and Hortle et al 2015 [which the EIA quotes earlier]), suggests that this will not be problematic because "During high flows, larvae apparently stay inshore and avoid drifting" (Vo 4-1 EIA page 110). This is a misinterpretation of the drift process in the Mekong: larvae do tend to drift nearer the margins to avoid turbulence but they are not active swimmers (being less than 20 mm in length with fins not fully formed) so cannot control the rate of drift. Also European species, including *Chondrostoma nasus* that is cited, do not have larval drift stages, so this is not a good comparison (see Fishbase https://www.fishbase.se/summary/Chondrostoma-nasus: "*Larvae occur below surface and feeding larvae inhabit along shores. Early juveniles live on the bottom in very shallow shoreline habitats. When growing, they move from the shore for faster-flowing waters. Juveniles overwinter in backwaters or in cavities along shores"*).

These conclusions underestimate the potential impact and importance of the fisheries in this region and more detailed studies are required to underpin the EIA procedures and establish practical mitigation measures.

In this context, the mitigation measures proposed are varied (Vol 4-1 EIA p110) and will not be repeated here, but they go beyond the classic stocking and aquaculture-based measures. The measures proposed are linked to management of fisheries exploitation, improving habitat, establishment of sanctuaries and training in reservoir fisheries management. There is also a proposal to "regularly observe the fish stocks at least twice a year on upstream and downstream sites" – the latter does not align with the quarterly assessment strategy indicated in the EMPP (Section 7.2). There is a concern over the proposal "Dam operation shall mimic the natural water regime to support persistence of pelagic spawning fish". There are no pelagic spawning species in the upper Mekong and there will likely be an open niche in the reservoir that will be exploited by non-native species. This suggestion needs reconsideration.

These measures are unlikely to compensate for lost fisheries production. They also do not address social and economic issues, fishery access issues or the need for alternative tools and techniques to catch fish. It is not known what funding is offered, but this is unlikely to compensate local fishing communities for disruption to food security and livelihoods. It is recommended:

- A thorough situation analysis should be carried out to determine the capacity of the local fishing communities to adapt to the potential changes that will arise from the proposed dam.
- There is also a need to undertake an alternative livelihoods analysis within the communities, again to identify opportunities for compensating losses incurred by the development.
- In addition, consideration needs to be given to mitigation measures that are commensurate with LPHPP being one of a cascade of HPPs. (see section 5.3). Rather than invest directly in mitigation measures at the LPHPP zone of influence, such as fishways that have no utility if there is insufficient habitat to complete the life cycles of the species present, spending may be better directed on offsets, like fishways on small irrigation structures, which could make a real difference. This concept needs considerable discussion with the Government of Lao PDR, developers, MCs, NGOs and experts to optimise any action taken and is only relevant to upper Loa cascade of dams.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Compliance with preliminary design guidance (PDG 2009)

This report reviewed all documents submitted for the LPHPP prior consultation process, but specifically the Executive Summary, EIA, CIA-TBIA and EMMP, and compiled a cross-check against the PDG (see Annex 2 of this report).

The LPHPP documentation provides a reasonable overview of the fish species diversity in the upper Lao reach but less so for the linkages with elsewhere in the LMB. This was based on MRC reports, data gathered during prior consultations for Xayaburi and Pak Beng and as part of the concession agreement during the development of Xayaburi HPP, four surveys restricted to five sites in 2019, plus some ARIS count data on fish movements. The documentation also describes the proposed fish passage facilities to move fish both up and downstream around LPHPP dam and infrastructure and measures to mitigate potential problems

The LPHPP documentation, however, falls short of expectation of compliance with the PDG (see Annex 2 for crosscheck list). Specific issues related to non-compliance are highlighted below. When evaluating compliance, due consideration was given to LPHPP being immediately upstream of Xayaburi HPP.

- The fish passage facilities are extensive and cater for fish approaching the dam in different places over the cross section of the river to accommodate different flow patterns and zones of fish attraction. However, in the documentation no other fishway options have been considered. The design favours surface-dwelling species and are inadequate for benthic species, while the spillway entrances do not accommodate different flow patterns and zones of fish attraction on the spillway (PDG Para 60-63). The proposals for downstream passage have weaknesses in relation to drift of larvae through the reservoir and mortality of fish passing through the trash screens, turbines and spillway. Currently, there is no possibility of assessing whether the fish passage facilities will function as expected according to the PDG.
- Weaknesses in the planning and design of the fishways are recognised, such as the size of the lock chambers (although the developer indicates the lock chambers are the same dimensions as Xayaburi HPP so consistent in design) and the relationship to downstream dams has not been fully explored (PDG Para 64-65), although the developer indicates the lock chambers are the same dimensions as Xayaburi HPP so consistent in design.

- Weaknesses in the ecological appraisal of the fisheries around LBHPP preclude any assessment of whether the fish passage facilities will cater for the diversity of species that inhabit this region, the variability in timing of migration (all year round), the volume of fish that will utilise the fish passage facilities and accommodate both upstream and downstream (especially of juvenile life stages) (PDG Para 66-71).
- Little information is provided on the hydrological and hydraulic conditions in and around the dam site and proposed fish passage facilities (PDG Para 72-84), although some modelling has been undertaken.
- Information on monitoring and evaluation (PDG Para 85-89) is superficial and needs a full specification to be provided, and an indication that all information will be shared for external scrutiny. No adaptation programme is envisaged and no contingency funds indicated should adaptation of the fish passage facilities be required.

7.2 Relevance of the Draft Preliminary Guidance (PDG 2019)

Although not mandatory for the LPHPP TRR, the prior consultation documentation was checked for relevance against the PDG 2019 (MRC 2019d) as a measure for good practice. The check is made against main headings rather than individual clauses.

Fisheries	
Clauses	**Comment on LPHPP submission**
Risks (181-189)	Review of the main risks to fisheries is provided but mostly relates to barrier effects and change in hydraulic conditions caused by the impoundment. Little about risks from external activities that directly or indirectly affect fisheries. No direct linkages to design and operation of fish passage facilities at Xayaburi and Pak Beng to maintain connectivity through the upper Laos cascade system.
Pre-Project Monitoring and Analyses(190-196)	Pre-project monitoring not considered sufficiently robust to determine impacts on fisheries as it is based on a single survey and is mostly lists of species diversity (although conservation status of species is reported), with minimal abundance data. It is not adequate to set a baseline for fisheries to assess the impact of the development on fish and fisheries or OAAs. Further modelling of hydrological and hydraulic conditions to inform selection of suitable fish passage options is required.

Specific Design and Operational Guidance (197-246)	A full array of mitigation options to address the issues are the dam infrastructure are considered but limited actions on enhancing downstream drift of larvae.
Habitats (200-204)	Position of dams does not affect any critical habitats except that required by rhithron species for survival and whitefish for spawning will likely be lost because of the cascade of dams.
Fish passage (205-208)	Fish passage designed for an array and high biomass of species.
Biological and hydrological criteria for fish passage design (209-211)	The proposed migration flows for fish passage design from minimum flows to 10,650m^3/s, which covers the anticipated migration period and matches the operating range of the Xayaburi HPP that is immediately downstream. The minimum flow for LPHPP is 793 m^3/s in the hydrology report and 1,170 m^3/s is used in fishway design. Further analysis of the impact of the upstream Chinese dams and climate change is required.
Upstream Fish Passage - Attraction (213-220)	The design favours surface-dwelling species and are inadequate for benthic species, while the spillway entrances do not accommodate different flow patterns and zones of fish attraction on the spillway. Some species of migrating fish will very likely not locate the proposed fishway entrances and fish passage will be ineffective for those species.
Upstream Fish Passage - Passage (221-230)	The fish passage facilities are extensive and cater for fish approaching the dam in different places over the cross section of the river to accommodate different flow patterns and zones of fish attraction. However, in the documentation no other fishway options have been considered.
Downstream Fish Passage (231-241)	The proposals for downstream passage have weaknesses in relation to drift of larvae through the reservoir and mortality of fish passing through the trash screens, turbines and spillway.
Fish Passage Operation (242-244)	No consideration given to enhance fish passage during operation.
Fish passage during construction (245)	Consideration given to using navigation locks.
Alternative mitigation measures and fisheries resource management offsets (246)	A range of mitigation options beyond fish passage facilities are considered but not all are considered realistic. There is need to consider mitigation options to accommodate issues likely to arise from the cascade of dams.

Project Monitoring and Adaptive Management (247-254)	A monitoring programme for fisheries is proposed in the EIA and EMMP, which is similar to that proposed for the pre-assessment but to build on the experience from Xayaburi HPP. As it stands information on monitoring and evaluation is superficial and needs a full specification to be provided. A range of management actions related to regulating the fishing activities are proposed.

7.3 Gaps and uncertainties

Details on disruption to fish migration: The MRC PDG implies there is a proportion of migratory fish species and sets targets for both upstream (primarily spawning adults) and downstream (returning adults and larvae/fry) passage. The developers have considered fish passage in both upstream and downstream, although the level of information submitted on the underlying assumptions and design of the measures is limited. There are no details on how the effectiveness of the fish pass will be monitored, particularly in terms of meeting the efficiency criteria of the fish passes for different fish guilds.

Details on fishway design are limited: The initial finding is that the design of both the upstream and downstream facilities may need significant revision to account for the full range and sizes of species that are likely to require the fishways (recognising the need to protect biodiversity), and to determine the accessibility of the fishways. Alternative studies of fishway designs may be required to determine the most effective approach; suggestions to optimise the design are included in this report.

Hydraulic information is limited: The above assessments need to be coupled with appropriate assessment of the hydraulic conditions likely to encountered in and around (entrances and exits) the fishways.

Hydrology, hydraulics and water quality aspects missing: The assessment in the feasibility study only covers fish passage around the dam structure, but does not address wider implications on fisheries of altered hydrology and hydraulics in the reservoir area and downstream of the dam, changes in water quality, and issues related to aquatic food chains in maintaining viable fish populations.

No information on the operating rules and hydrology associated with hydropower production at the dam is provided: This is a fundamental requirement to understand how the fish passes will function, and how the environmental conditions in the reservoir and downstream of the dam will be modified. This is also required to determine the effectiveness of any fish passage as it will be heavily influenced by the planned flow regime.

Limited information on mitigation, compensation measures and monitoring: The developer proposes a monitoring programme for fish and fisheries during the construction and operational phases similar to that carried out for Xayaburi HPP. Whilst some information on this monitoring programme is available, details of the different methodologies and how they will be used to build a picture of the baseline status and potential changes in the fish and fisheries are lacking. This requires a realistic, properly costed, monitoring programme. Similarly, there are no details on how the effectiveness of the fish pass will be monitored, particularly in terms of meeting the efficiency criteria of the fish passes for different fish guilds.

The existing study also requires mitigation and compensation measures to be better formulated and costed, as well as establishing an early warning system to be proactive to respond to potential impacts of the development.

Impact of multiple HPPs: More detailed reference to the cumulative impacts of the upper Lao cascade of HPPs on fisheries and aquatic biota is required. The cascade will transform the region from fast flowing lotic habitat to a lentic environment made up of a series of impoundments with little free flowing river suitable for spawning of rhithron and white fish species. In addition, the effects on fish having to bypass multiple dams, both upstream and downstream, needs detailed evaluation because it may impact the proposals for fish passage solutions, and whether such facilities are likely to be effective. This should, at minimum, include the potential cumulative impacts associated with the Pak Lay, Xayaburi and Pak Beng hydropower projects.

Transboundary issues: No comprehensive transboundary fisheries risk and impact assessment has been provided. Instead, the documents argue that LPHPP will not affect the lower Mekong, but this argument is focused on flows into the Tonle Sap only and does not consider the Mekong Delta. Whilst any flow impacts will be moderated by the Xayaburi HPP operational regimes, two elements need to be considered in more detail: viz. the cumulative impact of disruption to fish migration and reproductive capacity in the LMB, and the reduction in sediment flows, and the associated nutrient dynamics, on fisheries downstream in Lao PDR, Thailand, Cambodia and Viet Nam. Reference to the MRC Council Study will better inform this aspect.

No information on the social and economic impacts on fishing and rural communities: There is an absence of information on the direct and indirect impacts of the dam proposal on fishing community livelihoods and food security, or the indirect impact on sustainable livelihoods of affected rural communities. The impacts of LPHPP and the cascade of HPPs on food security and livelihoods in the region affected by the dam must be elaborated.

7.4 Recommendations

This report reviewed all documents submitted to the LPHPP PNPCA, but specifically the Executive Summary, EIA, CIA-TBIA & EMMP, and compiled a cross-check against the PDG (see Annex 2).

The LPHPP documentation provides a good review of the fisheries and aquatic resources in the LMB but is less explicit of the local resource potential in the LPHPP impact area. The main empirical information provided on which to determine any likely impact, and therefore formulate mitigation measures, are from one field monitoring survey conducted in the dry season, although it is acknowledged that further surveys have been conducted. The reports provide little baseline information on which to a make comprehensive evaluation of impacts or to formulate measures to mitigate any likely impact. There are gaps in knowledge about species diversity, patterns and drivers of migration, the scale of fisheries in the impact area, livelihoods analyses and fishing activities. The documents also do not provide comprehensive justifications for, and descriptions of, mitigation measures, with the exception of provisions for fish passage. The methodology used for the various fisheries-related studies already being undertaken should be improved and year-round studies should be designed to cover all migration periods.

A monitoring programme of fisheries has been proposed by the developer, but this lacks details and does not appear to include assessments of the efficacy of the fish passage facilities in both upstream and downstream. In addition to direct fisheries condition assessments, there is a need for tracking studies for a range of species and sizes of fish, although it is acknowledged much of this information can be sourced from ongoing studies at Xayaburi HPP by XPCL and Charles Sturt University. Considerable lessons have been learnt from this monitoring that have informed the design of the LPHPP. However, efforts should be made to conduct joint monitoring programmes between the two HPPs, especially to benefit from the tagging and tracking studies being carried out. This would provide insights of how fish and fisheries behave in response to the changing environmental conditions, and the extent to which migration patterns are altered or impeded by the proposed cascade of HPPs. Nonetheless dedicated studies need to be carried out at the site of LPHPP to provide insight as to whether fish find the entrance and proportions of fish that successfully ascend. This will help improve fishway design (see Section 4.3).

Downstream passage must also be monitored to understand limitations in this life history phase to maintain viable fish populations in the LMB. It should be noted that the tracking studies to determine the efficacy of Xayaburi fish pass indicated above are not currently part of the ongoing monitoring programme for Xayaburi and is a gap in knowledge.

Recommendations:

- **A robust fisheries monitoring programme to evaluate: i) the status and trends in fisheries (based the 10 MRC guild categories - Appendix 2) and OAAs, and ii) the effectiveness and efficiency of the fishway should be designed, with detailed methods and budgets. Mechanisms to ensure that the outputs of these studies are acted on, must be included.**
- **The documents submitted (including EIA, CIA-TBIA, fish passage design drawings and EMMP) need to be supplemented with additional information to allow for scientifically sound decision-making regarding the extent of the impacts of LPHPP on fisheries (local, transboundary and cumulative), and options to mitigate these impacts.**
- **There is need for a detailed budgetary breakdown into monitoring, mitigation and contingency plans during the construction and operational phases of the life cycle of the dam development.**

Details on fishway designs for both upstream and downstream passage require revision, as outlined in section 3. Alternative fishway designs may be required to determine the most effective approach; suggestions to optimise the design are included in this report.

Recommendation:

- **A more detailed technical analysis of both upstream and downstream fish passage facilities appropriate to all species, life history stages and sizes, including benthic species, should be carried out and mechanisms to improve the design and efficacy of fish passage solutions integrated into the dam design.**

Information on the socioeconomic and livelihoods dimensions specific to the fisheries sector are limited. There is a need for a detailed baseline study on the socio-economic impacts both in the immediate LPHPP reach and any transboundary areas likely to be impacted by the development, including analysis of the impact of the upper Lao cascade of HPPs. This is required to support the design of alternative livelihoods options, and the equitable distribution of the benefits within the impact area and in downstream reaches.

Recommendation:

- **There is a need for dedicated socio-economic studies on fishing households (including part-time and seasonal fishing households) and their dependence on fisheries for food security and livelihoods. In addition, there is need to determine dependency of rural and peri-urban communities on fish and OAA as primary dietary items and for nutritional requirements.**

The EIA and CIA-TBIA lack assessment of the implications of multiple dams in the upper cascade proposed in Laos and the interrelationships between dams on fish and fisheries (see section 5.1). Further, assessment of transboundary impacts of LPHPP on environmental and ecological systems further downstream in the Mekong are largely linked to the Tonle Sap and not the floodplain systems in southern Laos, Cambodia and Viet Nam, and this has not been modelled in relation to the change in habitats and implications on aquatic ecology and fisheries. Given the weaknesses in the cumulative and transboundary impact assessment, several recommendations are proposed.

Recommendations:

- **Comprehensive transboundary and cumulative fisheries impact assessments should be conducted by the developer. These assessments should include not only the impacts on fisheries but ecosystem functioning and involve a wider ecosystem services assessment.**
- **The developers should also make better use of MRC capacity to develop informative models of the likely impact of dam development on critical habitats and the impact on ecosystem functioning and services, including fisheries, in the LMB.**

In addition to these important assessments, there is an urgent need for a more fundamental review of the evidence concerning investment in fish passage facilities. If the river systems above the various dams will be compromised to the extent that they will no longer support the life cycle and habitat needs of the major migratory and rhithron species that make up the bulk of the catch, one has to question the value of building fish passes in HPP schemes in the upper Lao cascade into the future. This is not to say that installation of fish passage facilities can be abandoned, but that better use of the monies projected for fish passage infrastructure be invested in activities that will deliver better ecological outcomes should be considered. In the first instance, this would require a consultative workshop of all parties and stakeholders to debate the principles, likely impacts on fisheries and livelihoods, shifts in benefits to rural populations and how the any cost savings can be disbursed to benefit fisheries elsewhere. **Note: this scenario only applies to the Upper Lao**

cascade and should not be transferred to dams built elsewhere on the main Mekong River channel.

- **It is recommended a full review of the impact of the upper cascade of HPP and tributary dams on fish population and community dynamics is undertaken to determine the practicality of constructing fish passage facilities at future HPP dams in the Mekong upstream of Sanakham. The review should include environmental, ecological and social and economic attributes and not just be restricted to fisheries.**

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Appendix 2. Major Guild Types in the LMB (based on Welcomme et al. 2005 and MRC Technical Publication No. 25)

Guild ID	Guild Name	No. of Species	Preferred habitat type	Key Characteristics
1	Rhithron resident	6	Rhithron	• Resident in rapids torrents, rocky areas and pools in the rhithron. • Generally insectivorous, algal scrapers or filter feeders, small in size, lithophilic • or phytophilic with extended breeding seasons and suckers or spines to maintain position in the flow • Limited migrations.
2	Main channel resident	38	Marine to Rhithron	• Long distance migrants spawning in the main channel (sometimes in rhithron) • 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 utilising backwaters and slacks as nurseries. • Adults do not enter floodplain and may be piscivorous. • Lithophilic members may be anadromous with fry resident at upstream site for a certain period and may occupy upstream floodplain. • May also include psammophils (sand spawners). • Members vulnerable to overexploitation and tend to disappear when river is damned preventing longitudinal upstream migration. May respond favourably to fish passage facilities. • Includes anadromous species.
3	Main channel spawner	14	Floodplains to Rhithron	• Spawn in the main channel, tributaries or margins upstream of floodplain feeding and nursery habitat often with pelagic egg or larval stages. • Pelagophilic, lithophilic, phytophilic (in floodplain margins) or psammophilic. • Adults and drifting larvae return to floodplains to

				feed. • May migrate to refuges (deep pools) in the main channel during the dry season. • Tend to disappear when river is damned preventing longitudinal migrations to spawning and refuge habitat.
4	Floodplain spawner	26	Floodplains to potomon	• Undertake migrations from floodplain feeding and spawning habitat to refuges (deep pools) in the main channel during the dry season. • Predominantly phytophils. • Differ from main channel spawner in that spawning occurs on the floodplain with main channel used as refuge during dry season. • Threatened when river is damned preventing lateral and longitudinal migrations to refuge habitat in main channel.
5	Generalist	56	Floodplains and potomon	• Limited non-critical migrations in mainstream. • Highly adaptable, mobile and static elements in their genome make them highly adaptable to habitat modification. • Often repeat breeders or breed during both wet and dry seasons sometimes with nests and parental care. • Rheophilic or limnophilic; often tolerant of low dissolved oxygen concentrations • May be semi-migratory often with sedentary local populations. • Benthic members are predominantly lithophils and psammophils and occupy centre of main channel with intolerance to low dissolved oxygen. May seek refuge in deep pools during dry season. • The riparian zone members typically occur amongst the vegetation of the main channel and fringing floodplains. • May undertake lateral migrations to floodplain to occupy similar habitats during flooding. • Often tolerant and low dissolved oxygen and exhibit wide range of breeding behaviour but predominantly phytophils. • This guild is especially well represented in most

				rivers.
6	Floodplain resident	22	Floodplains	• Limited migrations between floodplains pools, river margins, swamps, and inundated floodplains. • Tolerant to low oxygen concentrations or complete anoxia. • Often repeat breeders, phytophils, nest builders, parental care or live bearers.
7	Estuarine resident	42	Estuary	• Limited migrations within the estuary in response to daily and seasonal variations in salinity. • Brackish water guild euryhaline and usually confined to brackish part of system. • Freshwater estuarine guild includes stenohaline species that inhabit freshwater component of estuarine system.
8	Semi-anadromous	3	Estuary and lower potomon	• Enters fresh/brackish waters to breed • Enters freshwaters as larvae/juveniles to use the area as a nursery, either obligate or opportunistic.
9	Catadromous	3	Marine to Rithron	• Reproduction, early feeding and growth at sea. • Juvenile or sub-adult migration to freshwater habitat often penetrating far upstream. Members vulnerable to over exploitation and tend to disappear when river is damned preventing longitudinal upstream migration. May respond favourably to fish passage facilities.
10	Marine	19	Estuary	• Enters estuaries opportunistically