FISH PASSAGE OPPORTUNITIES FOR THE LOWER SESAN 2 DAM IN CAMBODIA

Lessons from South America

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Image
Cover image: Travelling down the Lower Sesan (Photo Eric Baran). Inside page: Lower Sesan (Photo Eric Baran)

Project Team

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1 EXECUTIVE SUMMARY

The present study was conducted for the Water and Food Challenge Program project “Optimising the management of a cascade of reservoirs at the catchment level” (MK3). We review the cases of three fish passage systems at high dams in South America and draw lessons regarding the possible design of a fish passage system at the Lower Sesan 2 site, without modifying the current design of the dam.

Blocking the lower part of the Sesan and Srepok Rivers will clearly have a negative impact on biodiversity, fish migrations, fish catch and food security in the 3S area and far beyond. This calls for the construction of a fish pass at the Lower Sesan 2 site.

Studies of fish passage systems at high dams in South America showed that in a species-rich tropical environment, up to 116 species were found in the fish passage systems, with a few species (mostly excellent swimmers) predominating among those reaching the top.

The efficiency of the fish passage seems closely linked to the water velocity in certain stretches and suggests that a velocity of 2.3 m.s\(^{-1}\) is acceptable (with 0.8 m minimum depth and low turbulence). Discharge in the pass system should be between 10 and 12 m3.s\(^{-1}\) year round.

In order to improve the chances of a greater variety of species and a larger number of individuals passing successfully, the behaviour and swimming capabilities of the target fish species should be considered a research priority.

In terms of downstream migration of adults, a fish passage may be more successful if it is directly connected to a part of a reservoir that is flowing and well oxygenated (lotic or river-like conditions). More generally, the distribution of favourable habitats for reproduction upstream should be taken into account.

Last, efficient fish passage systems for high dams must mimic the natural systems in order to facilitate the maintenance of natural fish populations. A variety of biotopes along an extended fish passage system creates beneficial conditions for more species to pass the obstacle.

A review of local conditions at the Lower Sesan 2 site shows that the stream located 9.8 km downstream of the dam on the right bank would potentially be a good path to consider for the development of a fish passage system similar to that of the Canal da Piracema at the Itaipu Dam in South America. That fish pass would consume at most 1.2% of the reservoir water and result in a loss of hydropower not superior to 1.1% of the planned production.
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INTRODUCTION

The reproductive strategy of tropical migratory species usually involves spawning upriver. The eggs drift downstream, developing and hatching in typically turbid water, and the larvae are transported downstream to areas with shelter and food while the adults return downriver (Lowe-McConnell, 1987). This reproductive cycle is challenged by dams that obstruct migration routes (Marmulla, 2001; Dugan et al., 2010; Ferguson et al., 2011).

Fish ladders or other fish passage facilities are often recommended as a means to mitigate the lost connectivity between upstream and downstream areas. In South America, where 388 rivers are already dammed (Kareiva, 2012) a large number of such passes have been built and monitored, and their performance vis-à-vis tropical fish species has been documented in peer-reviewed publications (Agostinho et al., 2007b; Pompeu et al., 2012). This represents a significant body of experience that is highly relevant to dam impact mitigation in the Mekong Basin.

In Cambodia, the Lower Sesan 2 Dam (LSS2, 45m high) is the biggest hydroelectric project to date. It is located 40 km away from the Mekong River at the confluence of the Sesan and Srepok Rivers. Thus, this dam will block fish migration on two of the largest tributaries of the Mekong River and has been identified as the tributary dam having the biggest potential impact on fish production and fish biodiversity in the Lower Mekong Basin (Ziv et al., 2012). According to Ziv’s model, the Lower Sesan 2 Dam is likely to result in a 9.3% drop in fish biomass basinwide, i.e., a loss of about 195,000 tonnes a year. However, the project EIA simply states that “Due to geographical condition and economical feasibility, no fish pass will be installed in the Sesan 2 HPP” (see Text box 1).

One point is that very few fish passage systems are effective for dams higher than 30 metres. However, studies from South America have recently documented three cases of fish passes designed for high dams, in particular one whose design is compatible with dams already built.

In this report, we detail the characteristics of the Lower Sesan2 Dam and the main features of the Lajeado and Peixe Angical fish ladders and those of the Canal da Piracema. We review the main lessons regarding fish passage at these sites and relate them to the case of the Lower Sesan 2 Dam. In the last section, an analysis of the site configuration at LSS2 allows us to identify the streams most suitable for the development of a fish passage facility. This brief exploratory approach should pave the way for an in-depth analysis of the ways to actually mitigate the impact of the Lower Sesan 2 Dam on fish migrations and production without modifying the agreed upon design of this dam.

Text box 1: EIA viewpoint about a possible Lower Sesan 2 fish pass

“Due to geographical condition and economic feasibility, no fish pass will be installed in the Sesan 2 HPP. This means that the proposed dam will totally block upstream migration of fish. At least 52 species are long migratory species in the Cambodia Mekong Basin. They compose numerous families, genera, body shapes and structures. Thus, a specific type of fish pass could not accommodate the entire Cambodia Mekong migratory fish species. As raised by International Rivers in the Mekong Basin, there are no good examples of effective fish passes. There is no prospect that a fish pass could make a significant difference to the blocking effects of hydropower dam on fish migration. In addition, Baran et al. (2009) recommended that there are no fish passes that can accommodate the size and intensity of mainstream migrations in the Lower Mekong Basin. Probably a fish pass of more than 15 metres high could not accommodate the numerous migrating fish species of the Mekong Basin.”

PEC and KCC 2008, section 3.11.
3 THE LOWER SESAN 2 PROJECT

The Lower Sesan 2 was officially approved for construction on 4th November 2012 and is expected to enter commercial operations in 2017. This dam will be located 40 kilometres east of Stung Treng town and will block the connection between the Mekong and the Sesan and Srepok Rivers. The dam area is shown in Figures 1 and 2.

![Figure 1: Location map showing the Lower Sesan 2 Dam (red dot) in the Sesan River Basin.](image)

![Figure 2: Aerial view of the proposed dam site. Photo E. Baran](image)

The structure will consist of an 8 kilometre long homogenous earth-fill dam with a height of 83 m above sea level (masl) and a top width of 8 m. Five turbine units of 80 MW each for a total 400 MW capacity are planned for electricity production. The dam spillway will be rectangular (15 m x 16 m) and have 12 bays. The dam will include water intake, penstock, tailrace channel, buildings for administration and operation and a switch yard (PEC and KCC, 2008). With a planned water level of 75 m, the dam construction will create a reservoir extending over 335 km² and will be able to store 1.79
billion cubic meters of water. The main characteristics of the dam are summarised in Table 1 and illustrated in Figure 3.

Table 1: Characteristics of the Lower Sesan 2 Dam. Source: CNMC 2009.

<table>
<thead>
<tr>
<th>Location</th>
<th>Confluence of Sesan and Srepok Rivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>49,200 km²</td>
</tr>
<tr>
<td>Height</td>
<td>45m</td>
</tr>
<tr>
<td>Length</td>
<td>7,729 m</td>
</tr>
<tr>
<td>Active storage</td>
<td>378.4 mcm</td>
</tr>
<tr>
<td>Full supply level</td>
<td>75 mamsi</td>
</tr>
<tr>
<td>Low supply level</td>
<td>74 mamsi</td>
</tr>
<tr>
<td>Mean flow</td>
<td>1,304 m³/s</td>
</tr>
<tr>
<td>Installed capacity</td>
<td>480 MW (400MW being more commonly cited)</td>
</tr>
<tr>
<td>Peaking capability</td>
<td>120.5 MW</td>
</tr>
<tr>
<td>Mean annual energy</td>
<td>2,311.8 GWh</td>
</tr>
<tr>
<td>Firm annual energy</td>
<td>611 GWh</td>
</tr>
</tbody>
</table>
4 IMPACT OF THE LOWER SESAN 2 DAM ON FISH RESOURCES

The Lower Sesan 2 Dam will block connectivity between the Mekong mainstream and two of the three rivers of the 3S system. The 3S system has been recognised as a major contributor to the fish biodiversity and fish productivity of the Mekong, as detailed below.

In terms of fish biodiversity, the 3S system (Srepok, Sesan and Sekong Rivers) is home to 329 fish species, which represents 42% of all Mekong fish species, although the basin area represents only 10% of the Mekong Basin area (Baran et al., 2011). Among Mekong endemic species, 45 are found in the Srepok River and 24 in the Sesan River. More specifically, two species (*Sinibrama affinis* and *Toxabramis hotayensis*) are found only in the Srepok River and in no other part of the Mekong. According to the EIA, five endangered fish species are found in the project area, including one (*Probarbus jullieni*) listed on the CITES.

Fish migrations are an important feature of the Sesan and Srepok Rivers; the analysis detailed in Baran et al. (2011) shows the 3S system is characterised by at least 89 migratory fish species belonging to 15 families. Out of 133 fish species in the Sesan River, 54 are migratory, and out of 240 species in the Srepok River, 81 are migratory (only 34 are recognised in the EIA section on fisheries). At least 41 migratory fish species are commonly caught by fishermen in the Sesan River, and these migratory species represent 60% of the fishermen’s total catch. The main fish migration patterns in the 3S are illustrated in Figure 4. Despite differences between the number of migratory species identified in Baran et al. (2011) and that in the EIA section on fisheries (PEC and KCC, 2008), the importance of migratory species in these two rivers is well recognized in both studies (see Text box 2).

**Text box 2: Conclusions of the LSS2 EIA executive summary about fisheries**

“Impacts on fish will be severe as many species are migratory (around 66%) and their passageway through the project area will be blocked by the dam. This will also have impacts downstream of the dam into the Mekong River and potentially also the Tonle Sap Lake as this is where some fish migrate to/from. The impacts on fish will occur whatever the dam size as it will block fish passage through the dam site, some species may disappear or change and there shall be potentiality of natural fish yield’s reduction.”

PEC and KCC, 2008, Executive Summary
Figure 4: Main fish migration pulses in the 3S. Drawing based on the information presented in Baird and Shoemaker, 2008
The above quote in Text box 2 underlines the likely impact of the LSS2 Dam on the Mekong and Tonle Sap fish resource; this is due to the fact that about half of the overall Mekong fish production (i.e., 2.1 million tonnes per year) is harvested in downstream floodplains (Tonle Sap and the delta) and at least 39% of this biomass is made up of long-distance migratory fishes (Baran, 2010). The 3S watersheds happen to be major breeding zones for long-distance migratory species, and these zones are connected to the fish production zones through four “migration highways”: the Mekong mainstream (subject to the Khone Falls migration bottleneck), and the Sekong, Sesan and Srepok Rivers (Figure 5). The Lower Sesan 2 Dam will thus block two of the four main Mekong migration highways, resulting in impacts on fish resources extending far beyond the project area. This is the point, peer-reviewed via the US Academy of Science, that led Ziv et al. (2012) to the conclusion that the Lower Sesan 2 Dam would result in a 9.3% drop (i.e., about 195,000 tonnes) of the Mekong annual fish yield.

**Figure 5: Schema of the four migration highways between the main fish production zone and migratory fish reproduction zones.**

**Fish consumption** is another important feature along the Sesan and Srepok Rivers. A recent study by IFReDI (2013) surveyed consumption of fish nationwide, including in the mountains and plateaus that the 3S is part of. The study concluded that people in mountains and plateaus consume on average 52.3 kg of fish and other aquatic animals per person and per year (the proportion is higher along rivers). Out of this, inland fish represent 26.5 kg/person/year (Table 2). These figures are based on extensive field surveys and are therefore more solid than the previous estimates reviewed in Baran et al. (2011) which ranged between 15 and 334 kg/person/year. These data also confirm that the proportion of migratory species in the daily diet of fish for people in the “mountains and plateaus” ecozone reaches 58% (in particular 45% for long-distance migrants, see Figure 6).

**Table 2: Consumption of fish and other aquatic animals (OAAs) in the “mountains and plateaus” ecozone.** Source: IFReDI 2013

<table>
<thead>
<tr>
<th></th>
<th>Grams/person/day</th>
<th>Kg/person/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black fish (non-migratory species)</td>
<td>30.3</td>
<td>11.1</td>
</tr>
<tr>
<td>White fish (long-distance migratory species)</td>
<td>32.7</td>
<td>11.9</td>
</tr>
<tr>
<td>Fish Category</td>
<td>Proportion</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>Grey fish (local migratory species)</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>Inland other aquatic animals</td>
<td>14.7</td>
<td></td>
</tr>
<tr>
<td>Aquaculture fish</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Marine fish</td>
<td>51.8</td>
<td></td>
</tr>
<tr>
<td>Marine other aquatic animals</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>143.2</strong></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6: Proportion of migratory fish in the inland fish consumption of people in the “mountains and plateaus” ecozone. Source: IFReDI 2013.

5 FISH PASSES FOR HIGH DAMS IN SOUTH AMERICA

In the following sections, we review three South American fish passes designed for dams that are 30m high or more. We draw lessons from these passes in order to inform the possible design of a fish pass at the Lower Sesan 2 Dam site.

5.1 FISH PASSAGE SYSTEMS REVIEWED

The three fish passes reviewed are:

- **The fish ladder at Peixe Angical Dam**: a weir and orifice ladder located at the upper Tocantins River in Brazil. It is 576 m long with total elevation gain of 30 m.

- **The fish ladder at Lajeado Dam**: a weir and orifice ladder located at the middle stretch of the Tocantins River in Brazil. It is 874 m long, with a total elevation gain of 36.8 m.

- **The Canal da Piracema at the Itaipu Dam**: a fish pass located at the border between Brazil and Paraguay (see description below). The pass is 10 km long and the total elevation gain is 120 m.

Figure 7: Location of the three South American fish passages reviewed.
We detail in particular the case of the Canal da Piracema (Text box 4) since it would be the technical option most relevant for a 45m high dam such as Lower Sesan 2.

**Text box 3: Fish ladders at the Peixe Angical and Lajeado Dams**

*Sources: Agostinho et al., 2007a; Agostinho et al., 2011; and Pelicice and Agostinho, 2012.*

The fish ladder at Peixe Angical Dam is 576 m long and 5 m wide, with a 5% slope and a total elevation gain of 30 m. The ladder consists of 64 weirs with submerged orifices (0.8 x 0.8 m), interspersed with two surface sills (0.5 x 1.0m) and five resting pools.

The fish ladder at the Lajeado Dam is 874 m long and 5 m wide, with a 5% slope, for a total elevation gain of 36.8 m. The ladder consists of an attraction channel (98m to the first weir) and 92 weirs with submerged orifices, interspersed with two surface sills and five still water resting pools.

The combination of weirs and orifices in fish ladders represents an improvement designed specifically in South America in order to better accommodate the diversity of the fish fauna and the presence of upper and lower orifices allowing the passage of species with different behaviours and swimming capabilities.

**Text box 4: the Canal de Piracema at the Itaipu Dam**

*Sources: Fiorini et al., 2006; Makrakis et al., 2007; Makrakis et al., 2011; Makrakis and Makrakis, 2012; Makrakis et al., 2012; and Fontes Jr. et al., 2012.*

The Canal da Piracema fish passage was completed in 2002 in order to mitigate the habitat fragmentation caused by the Itaipu Dam built 20 years earlier. It links the Paraná River with the dam reservoir. This fish passage system consists of a natural channel followed by four fish ladders and four artificial lakes aimed at allowing fish to rest. Altogether, this fish passage system is 10 km long and 120 meters high, which makes it the longest and the highest in the world.
5.2 **UPSTREAM MIGRATIONS**

Fernandez et al. point out that environmental stimuli such as temperature, velocity, discharge and river level, play a key role in upstream migration. Discharge is a key factor in the attraction of fish to the entrance of the fish pass, and velocity determines the success of fish trying to ascend it. Optimising water velocity is complicated given the various swimming abilities of the different species. The discharge used to attract fish towards a ladder also has to be considered in relation to discharge competition from turbines and the spillway (Fernandez et al, 2007a).

Pompeu et al. evaluated 16 fish passes in South America and found that most fish passes allowed about 60% of the downstream species to pass the obstacle at some time. However, they also noted that in all passes three to five species were predominant, comprising at least 70% and often over 80% of the catches (Pompeu et al., 2012).

5.2.1 **UPSTREAM MIGRATIONS AT THE LAJEOADO DAM FISH LADDER**

Agostinho et al. (2007b) studied the selectivity of species ascending the fish ladder at the Lajeado Dam between 2002 and 2003. Out of a total 130 species recorded downstream from the ladder, 62.3% were caught in the ladder, with migratory species predominating1. Nearly 70% of the catch, however, belonged to only three species. The study noted a sharp reduction in the abundance of fish at the top of the ladder. The richness and abundance of fish below and in the ladder varied with the water level, the lowest abundance corresponding to low water levels. Another study at the same site found that 98% of fish in the ladder had gonads in the pre-vitellogenic stage (i.e., were not sexually mature; Agostinho et al., 2007c). It was concluded that species composition and abundance in the ladder were not congruent with those downstream of the ladder and that selectivity was a key issue.

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1An additional study in 2007-2008 (Agostinho et al. 2011) led to the conclusion that 75% of species would use the ladder to move upstream (i.e. 50 species out of 67).
considering the objective of conserving fish biodiversity (Agostinho et al., 2007b). The latter study also found that a maximum flow velocity of 2.3 m.s\(^{-1}\) was more appropriate for upstream fish movement than higher velocities.

### 5.2.2 Upstream Migrations at the Peixe Angical Dam Fish Ladder

Pelice and Agostinho (2012) monitored ascending and descending fish movements through the fish ladder at the Peixe Angical Dam. Sites upstream, downstream and in the ladder were sampled for fish fauna over a one-year period. The results showed that the ladder restricts both upstream and downstream fish movements. Out of 119 species recorded in the area, only 31 were found to use the ladder.

### 5.2.3 Upstream Migrations at the Canal da Piracema Fish Passage

Prior to the construction of the Canal da Piracema a study was carried out between 1995 and 1997 at an experimental fish ladder near the Itaipu Dam. Twenty-two species were recorded as using the facility, out of which five species comprised 87% of the total catch (Fernandez et al., 2007b). Analysis of fish abundance at different places along the ladder clearly indicated a lower abundance in the upper part of the facility (Fernandez et al., 2007b). A similar pattern was noted at the fish ladder at the Lajeado Dam (Agostinho et al., 2007b). The migratory species that were found to ascend the Canal da Piracema with least difficulty were the excellent swimmers, which suggests that the fish passage may have a selective effect on other migratory species (Makrakis et al., 2007).

Once the Canal da Piracema was constructed, Makrakis et al. found that 116 species used that facility, including 17 long-distance migratory species. These migratory species represented 3.8% of the total abundance (i.e., 21,987 individuals sampled; Makrakis et al., 2007). As noted during the experimental phase and at the Lajeado Dam fish ladder, the highest number of migratory species was caught at the lower end of the canal and decreased in the upper parts of the fish passage system.

**Text box 5: Seasonality at Canal da Piracema**

Reproductive migrations of some species in the Paraná River basin are mainly synchronised with the flood period. High water levels in the river during the rainy season, high temperature during the hottest months of the year (from September to March in Brazil) and length of the day (photoperiod) are known stimuli of reproductive migrations. However, migrations also take place for trophic or dispersal reasons. Overall, the patterns of space and time utilisation by fishes in lotic environments are highly variable and differ not only among species but also between the different phases of their life cycles.

Regardless of their motivation, migratory species are more abundant in Canal da Piracema when the water level is high in the Paraná River. During the wet season the downstream water level rises significantly (up to 10 m, depending on the year) and this is the main factor explaining the abundance of migratory fish at the downstream entrance of the pass. Ascension of fish along the pass is then influenced by the water level in the reservoir. Observations at the Lajeado, Canoas I and Canoas II Dams fish ladders and the Mucuri Dam fish lift, in different hydrographic basins, confirm these conclusions.

At Lower Sesan 2 Dam, fish migrating upstream are likely to exhibit a similar pattern, with an increasing abundance associated with increasing water levels downstream of the dam, i.e., between May and August.

The first and second segments of the Canal da Piracema were found to present a particular obstacle to fish passage due to improper hydrodynamic features, including water velocity, shallow rock-free areas and high turbulence (Makrakis et al., 2007). Maximum water velocity was found to be the most influential variable negatively affecting the ascension of fish (Makrakis et al., 2011). From that perspective, the first segment of the Canal da Piracema presented difficulties to fish, with only 30% of the fish being able to reach the second segment under water velocity conditions exceeding 3 m.s\(^{-1}\) (Makrakis et al., 2011). This is consistent with the finding of Agostinho et al. (2007b) at the Lajeado Dam fish ladder (see section 4.2.1 above).
The selectivity of the second segment was studied using tagged fish (two species of Characiformes) released both downstream and upstream of the section (Fontes Jr. et al., 2012). The study showed that a smaller proportion of individuals released downstream of segment 2 reached the reservoir compared to individuals released upstream of segment 2 (18% vs. 60.8% respectively). Results also showed that fishes released downstream of the 200 m long segment 2 took an average 27 days longer than those released upstream to reach the upper end of the fish passage system (i.e., 43.6 days compared to 15.9 days). The delay may potentially interfere with spawning of the passing fish, since migrating fish need to reach feeding or spawning areas at specific times and thus must move during relatively short periods. (Makrakis et al, 2011, Fontes Jr. et al., 2012)

Last, Makrakis et al. (2011) found that only 0.5% of the number of migratory fish that entered the lower end of the Canal da Piracema were able to reach the upper part of the canal near the Itaipu reservoir. Although 17 of 19 known long-distance migratory species in the Paraná River Basin were found to be attracted to the Canal da Piracema, only two of the 17 species collected in the lower part of the canal were also recorded in the upper part near the Itaipu reservoir. However, a later design modification, including the construction of four additional deflectors, reduced in part the selectivity and increased the presence of migratory species above segment 2 (Fontes Jr., pers. comm.).

### Text box 6: Water requirement and design criteria of the Canal da Piracema passage system

The operation of the Canal da Piracema depends on the water level of the upstream reservoir. In optimal conditions the fish pass system requires a continuous flow of 10 to 12 m³.s⁻¹ year round (usually 11.4 m³.s⁻¹). This corresponds to only 0.1% of the average flow of the Paraná River at the same site.

Although the discharge of the Paraná River varies seasonally, that of the pass should be relatively constant. In case of water shortage the system can operate with reduced flows during the six drier months of the year corresponding roughly to the non-reproductive migration period. In such cases a minimum flow of 5 to 6 m³.s⁻¹ is considered desirable for the pass entrance to remain attractive to fish. Some years, when the Itaipu reservoir water level was too low, discharge in the pass was reduced to 0.5 m³.s⁻¹. Twice in 10 years the fish pass was temporarily interrupted due to extreme drought conditions.

For a dam smaller than Itaipu – such as Lower Sesan 2 - it is possible that the fish pass system works even at smaller dimensions, and thus with a lower water consumption, but this should be evaluated based on studies aimed at defining design criteria.

In the case of Canal da Piracema, the design criteria required for dimensioning of the structures were provided by fish experts. These include in particular (i) mean velocities in the transversal sections along the entire system not exceeding 3 m.s⁻¹; (ii) minimum water depth of 0.8 m under normal flow conditions in the sections between the obstacles; and (iii) wetted cross section areas not smaller than 4 m².

### 5.2.4 LESSONS FOR THE LOWER SESAN 2 SITE

The efficiency of the fish passes reviewed seems closely linked to water velocity in critical stretches. A velocity of 2.3 m.s⁻¹ is acceptable - although already selective - and a higher velocity would further limit fish ascension. It is recommended that the velocity never exceeds 3 m.s⁻¹ in long stretches. Maintaining velocities lower than 2.3 m.s⁻¹ would possibly cater for more species, but such an option would depend on the location and physical features of the path identified for the Lower Sesan 2 site.

Water level in the pass should be at least 0.8 m. The water level in and below the ladder and the nature of the substrate are other factors likely to influence the efficiency and selectivity of the pass.

The pass system should include resting areas with reduced or no turbulence hindering the swimming.

Prior to any construction, the behaviour and swimming capabilities of the target fishes in the Sesan and Srepok Rivers should be reviewed, and after construction the efficiency of the pass should be tested and the design revised accordingly.
5.3 **DOWNSTREAM MIGRATIONS**

The knowledge of the actual migration taking place in tropical fish ladders and fish passages is limited and has mostly focused on the success of species moving upstream (Pelícice and Agostinho, 2012). But to be effective in conserving fish species, fish ladders “must provide a fully permeable connection and assure both upward and downward movements” (Agostinho et al., 2007a).

Few studies have addressed downstream passage of fish, eggs and larvae through dams and fish passes, but indications are that downstream passage at large dams may be more complex than upstream migration (Halls and Kshatriya, 2009; Pelícice and Agostinho, 2012). The lentic characteristics of reservoirs hinder the downwards drifting of eggs and larvae, which may sink to the bottom or be subject to predation before reaching the dam, while adult migratory fish are found to favour the moving water at the upper part of a reservoir and upstream, where more lotic conditions exist (Pelícice and Agostinho, 2012; Pompeu et al., 2012; Agostinho et al., 2007a).

### 5.3.1 DOWNSTREAM MIGRATIONS AT THE LAJEADO DAM SITE

A study of the downstream dispersal of migratory fish and their offspring through the Lajeado Dam and reservoir (Agostinho et al., 2007a) showed that fish eggs and larvae from upstream did not make their way to the lower half of the reservoir and did not reach the dam. The eggs and larvae found in the water passing through the spillways, turbines and fish ladder at the dam belonged to non-migratory clupeids found in the reservoir. Conversely, larvae of migratory Characiformes and Siluriformes comprised the majority of those found above the reservoir in the same period. Sedimentation or sinking of eggs down to the bottom of the reservoir, in oxygen-poor or anoxic conditions, as well as increased predation in the clearer reservoir waters, were considered likely reasons for the lack of downstream dispersal of eggs and larvae (Agostinho et al., 2007a). In line with these considerations, Godinho and Kynard (2009) describe the protection of eggs and larvae drifting into large reservoirs as a significant challenge for fish conservation scientists. Agostinho et al. concluded that there is no indication that upward migrating fish return to their points of origin and that it is unlikely that eggs and larvae reach and pass through the dam to downstream areas (Agostinho et al., 2007a).

In an additional study, Agostinho et al. (2011) showed that downstream passage at the Lajeado fish ladder was very limited: 99.5% of the fish captured in the ladder were ascending the facility, the descending to ascending ratio being 1 to 1,508 on average (although that ratio was higher for migratory species). The study led to the conclusion that the fish pass only facilitates upstream migration movements.

### 5.3.2 DOWNSTREAM MIGRATIONS AT THE PEIXE ANGICAL DAM SITE

Pelícice and Agostinho (2012) monitored ascending and descending fish movements through the fish ladder at the Peixe Angical Dam.

Downstream movement amounted to just 4% of a total 17,335 individuals, thus indicating that the ladder failed to support downstream fish passage. It was concluded that the fish ladder at Peixe Angical Dam does not facilitate conservation of fish.

### 5.3.3 DOWNSTREAM MIGRATIONS AT THE ITAIPU DAM SITE

At the Itaipu reservoir, a survey of the ten key species in the commercial fishery between 2001 and 2003 showed that the migratory species were generally caught in the upper half of the reservoir where there are still some riverine characteristics. In the lower part of the reservoir, the catch consisted mainly of sedentary species (Agostinho et al., 2007a). This finding explains the low numbers of adult fish migrating downstream, as observed by Agostinho et al. (2011) and Pelícice and Agostinho (2012) at the Lajeado Dam and Peixe Angical Dam. It should be noted, however, that some adult specimens of migratory species tagged about 400 km upstream (at Porto Primavera fish ladder) were recorded by PIT telemetry in the Canal da Piracema. Overall, downstream passage may occur through the fish pass itself or through the structures of the dam and requires further evaluation.

### 5.3.4 LESSONS FOR THE LOWER SESAN 2
The limited downstream migration of adult fish, as well as eggs and fry, at the South American fish passages reviewed should be considered in relation to the location of a fish passage for the LSS2. A fish passage would be more successful at attracting adult fish for downstream migration if it were directly connected to a part of a reservoir with lotic conditions or near a major upstream tributary. Reduced downstream dispersal of eggs and fry is an impact whose mitigation would not be based on fish ladders and remains to be addressed. From that perspective, dams with smaller reservoirs would have less of an impact on native fish populations than those with extensive reservoirs.

6 OPTIONS FOR A FISH PASSAGE AT THE LOWER SESAN 2 DAM SITE

Lessons from South American fish passages provide important lessons regarding a possible fish passage for the Lower Sesan 2 Dam. In the section below, we review the possible location for a fish passage that would not modify the design of the dam itself. It should be noted that the present approach is exploratory, and the channels explored here should be subject to further studies to determine their feasibility and their appropriateness for target species.

Based on the experience of the Canal da Piracema, we looked downstream of the Lower Sesan 2 Dam at streams and creeks that might allow fish, after proper engineering, to pass the dam and reach the reservoir.

These streams were identified using GIS and Google Earth: a network of streams was transferred from GIS onto a Google Earth background map, together with an outline of the reservoir and the location of the dam site (Figure 8). In that figure the pink lines highlight the three paths that could be used as fish passages. These paths actually connect natural streams flowing (i) towards the Sesan River downstream of the dam and (ii) towards the reservoir. Connections between these natural channels are illustrated with a thicker pink line. We also used the Google Earth tool “show elevation profile” applicable to river paths in order to identify the lowest and highest points on each path (Figure 9).

The characteristics of the paths are identified in Table 3.

Table 3: Characteristics of the paths identified for the passage of the Lower Sesan 2 Dam

<table>
<thead>
<tr>
<th>Path</th>
<th>Length (km)</th>
<th>Lower end (m)</th>
<th>Highest point (m)</th>
<th>Higher end (m)</th>
<th>Altitude Difference (m)</th>
<th>Slope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>29.8</td>
<td>60</td>
<td>153</td>
<td>92</td>
<td>32</td>
<td>0.11</td>
</tr>
<tr>
<td>B</td>
<td>13</td>
<td>62</td>
<td>103</td>
<td>82</td>
<td>20</td>
<td>0.15</td>
</tr>
<tr>
<td>C1</td>
<td>17.6</td>
<td>57</td>
<td>119</td>
<td>84</td>
<td>27</td>
<td>0.15</td>
</tr>
<tr>
<td>C2</td>
<td>24.3</td>
<td>56</td>
<td>112</td>
<td>84</td>
<td>28</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Out of four potential passage paths, three would be very long (length between 17 and 30 km), i.e., 1.5 to 3 times longer than Canal da Piracema, and therefore unrealistic.

One of the paths (path B in Figure 9) would be 13 km long, i.e., close to the total length of Canal da Piracema. It would start 9.8 km downstream of the dam on the right bank and would reach the reservoir about 5.5 km away from the spillway. The average slope would be 0.15%, i.e., quite passable for most species. However, that path would require digging a 5.5 km canal connecting the two natural streams, between altitudes of 99 and 90 meters. That path offers a realistic option for mitigating the impact of the Lower Sesan 2 Dam on fish migrations and is certainly worth exploring further.
Figure 8: Streams that could be used for fish passage at the Lower Sesan 2 Dam site. Background image from Google Earth.
Figure 9: Elevation profiles of the three paths identified for the passage of the Lower Sesan 2 Dam. Background image and profiles from Google Earth
Since the fish pass requires a certain water flow that is taken from the reservoir and thus is not available for electricity generation, we review in this section the impacts of the fish pass on water flows and on energy production. The following analyses are based on a modelling approach initially developed to estimate trade-offs between irrigation and hydropower generation.

The modelling approach consists of catchment scale hydrological modelling using the VMod distributed hydrological model (Koponen et al., 2010) to calculate daily flows at dam site. Hydropower operation and energy production were simulated on a weekly basis using the CSUDP generalised dynamic programming tool (Labadie, 2003). The conceptual map of the model is shown in Figure 10. The hydrological data used to drive and calibrate the hydrological model as well as the characteristics of the hydropower project for hydropower simulations were obtained from Mekong River Commission’s hydrological and hydropower databases (MRC, 2009, 2011). The flow data used correspond to the January 2002 - December 2006 period. The modelling approach, detailed in the chapter on trade-offs in multipurpose reservoirs, has already been successfully applied in the Mekong Region (e.g., Räsänen et al., 2012).

Three hypotheses regarding water flow were considered (Table 4), by analogy with fish pass water requirements at Canal da Piracema, summarised in Text box 6.

- **H0**: baseline situation without fish pass in place.
- **H1**: fish pass in place with a constant 12 m$^{3}$.s$^{-1}$ flow.
- **H2**: fish pass in place with a 6 m$^{3}$.s$^{-1}$ flow during the dry season and 12 m$^{3}$.s$^{-1}$ during the rainy season.

Reduction in water availability and subsequent loss in energy production in the case of hypotheses H1 and H2 were compared against H0, using the 2002-2006 period as a basis for modelling.

**Table 4** Hypotheses for fish pass flows in the assessment. Flow units are in m3.s-1
The design flow for power plant is 2119.3 m³.s⁻¹ (MRC, 2009). In the simulations for H0, H1 and H2 all 11 dams existing and planned in the Sesan River were considered operational, resulting in dry season flows at dam site which were slightly higher than natural flows without dams. Hydropower development in the Srepok River was not considered. For each hypothesis the dam operations were optimised so that the annual hydropower generation was maximised.

### 6.1 WATER CONSUMPTION

For each of the three hypotheses, we show in the table below the annual water requirement of the fish pass and annual water availability during an average, a wet and a dry year. The percentage of water reduction for H1 and H2 by comparison with H0 is indicated between parentheses.

<table>
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<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H0</td>
<td>0</td>
<td>40.7</td>
<td>44.6</td>
<td>31.3</td>
</tr>
<tr>
<td>H1</td>
<td>0.4</td>
<td>40.3 (-0.9%)</td>
<td>44.2 (-0.8)</td>
<td>30.9 (-1.2%)</td>
</tr>
<tr>
<td>H2</td>
<td>0.3</td>
<td>40.4 (-0.7%)</td>
<td>44.3 (-0.6)</td>
<td>2.0 (-0.9%)</td>
</tr>
</tbody>
</table>

Thus, the water consumed by the fish pass would reduce water availability at power plant by 0.6% (best case scenario) to 1.2% (worst case scenario) maximum. A detailed weekly analysis shows that the maximum flow reduction would happen in the dry season (April-May) but would not exceed 3.5% during these months even in the worst case scenario.

### 6.2 LOSS IN HYDROPOWER PRODUCTION

We show in and for the three hypotheses the modelled loss in power due to water consumption by the proposed fish pass (Table 6 and Figure 11); forecasts are detailed for an average, a wet and a dry year. The percentage of power loss for H1 and H2 by comparison with H0 is indicated between parentheses.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>H0</td>
<td>2218</td>
<td>2309</td>
<td>2003</td>
</tr>
<tr>
<td>H1</td>
<td>2198 (-0.9%)</td>
<td>2296 (-0.6%)</td>
<td>1980 (-1.1%)</td>
</tr>
<tr>
<td>H2</td>
<td>2204 (-0.6%)</td>
<td>2296 (-0.6%)</td>
<td>1987 (-0.8%)</td>
</tr>
</tbody>
</table>
The water consumed by the fish pass would reduce power production by 0.6% (best case scenario) to 1.1% (worst case scenario). The model shows that the maximum loss of energy would happen in the dry season (April) but would not exceed 3% even in the worst case scenario.

8 CONCLUSIONS

Blocking the lower part of the Sesan and Srepok Rivers will clearly have a negative impact on biodiversity, fish migrations, fish catch and food security in the 3S area and far beyond. This calls for the construction of a fish pass at the Lower Sesan 2 site, while bearing in mind that the project is already approved and that its main design cannot be modified. Three fish passage systems in South America offer important insights into the opportunities and challenges of establishing a successful fish passage at the Lower Sesan 2 site.

Studies in South America showed that in a species-rich tropical environment, up to 116 species were found in the fish passage systems, with a few species (mostly excellent swimmers) predominating among those reaching the top. This underlines the fact that the fish pass might be considered more or less successful depending on the objectives stated: either limited success for overall biodiversity conservation or, on the contrary, good success rate for protection of a few target species (e.g., good swimmers such as Pangasiid catfishes) contributing to commercial fish catches.

The success of the fish passages reviewed seems closely linked to the water velocity in certain stretches. The review suggests that a velocity of 2.3 m.s⁻¹ is acceptable to many neotropical species, but that studies aimed at achieving a lower water velocity should be undertaken since that might cater to more species.

In order to improve the chances of successful passage for a greater variety of species and a larger numbers of individuals, the behaviour and swimming capabilities of the target fish species should be considered a research priority. In addition to applying this knowledge in the planning and location of
the fish passage, it will also be important to establish continuous monitoring and evaluation so that the design of critical sections of the fish passage can be improved.

Experience from South America also shows that the sustainability of fish stocks also depends on the size of the dam reservoir: large reservoirs hinder the survival of eggs and fry during their downstream migration, regardless of the performance of the fish pass vis-à-vis the upstream migration of adults. In terms of downstream migration of adults, a fish passage may be more successful if it is directly connected to a part of a reservoir that is flowing and well oxygenated (lotic or river-like conditions). More generally, the distribution of favourable habitats for reproduction upstream should be taken into account (Fernandez et al., 2007a; Pompeu et al., 2012).

Downstream dispersal of eggs and fry is an issue that should be further studied. More generally, the focus on upstream migration has overshadowed the need for a solid understanding of downstream migrations and the completion of lifecycles. In that regard, fish ladders “should be viewed as an operational management tool based on a complete spatio-temporal understanding of fish populations” (Fernandez et al., 2007b).

Lastly, efficient fish passage systems for high dams must mimic natural systems in order to facilitate the maintenance of natural fish populations (Pompeu et al., 2012). A variety of biotopes along an extended fish passage system seems to create beneficial conditions for more species to pass the obstacle. Thus, Makrakis et al. (2007) argue that nature-like fish passes that attempt to simulate a natural flow have several advantages compared to traditional ones, in that they usually encompass heterogeneous structures that offer varied velocities and depths and thereby cater to a greater variety of species and fish sizes.

A review of local conditions at the Lower Sesan 2 site shows that the stream located 9.8 km downstream of the dam on the right bank would potentially be a good path to consider for the development of a fish passage system similar to that of the Canal da Piracema at the Itaipu Dam. That fish pass would consume at most 1.2% of the reservoir water and result in a loss of hydropower not superior to 1.1% of the planned production.
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