Mekong River Commission

Guideline
to
Prioritising Fish Passage Barriers
and
Creating Fish Friendly Irrigation Structures

Lower Mekong Basin

November 2014

Tim Marsden
Australasian Fish Passage Services
tim.marsden@ausfishpassage.com

Claire Peterken
Claire Peterken Consulting
Claire.peterken@gmail.com

Lee Baumgartner
Murray Darling Freshwater Research Centre
Latrobe University
L.Baumgartner@latrobe.edu.au

Garry Thorncraft
Faculty of Agriculture
National University of Laos
garrythorncraft@yahoo.com.au

Contents

Executive summary

The Lower Mekong Basin supports the health and wellbeing of 60 million people, many of whom rely on the fisheries production of the system for food and income. The river fisheries of the region provides a major source of protein for this population, making the sustainable use of this resource critical to the ongoing wellbeing of the population.

Within the Lower Mekong Basin there are over 1400 species of fish, with the vast majority of these species undertaking movements up and down the river system throughout the year and out onto the floodplains during flood events. They undertake these migrations to reach spawning areas, disperse into new habitats or to access food resources. Without the free movement of fish throughout the basin, fisheries productivity is likely to decline. Throughout the Lower Mekong Basin tens of thousands of barriers to fish movement have been constructed. Dams, weirs, regulators, floodgates and road crossings may all form steps in the river too high for fish to pass. These barriers are often constructed to improve agricultural productivity through the storage of water for irrigation. These barriers have a significant impact on fish, they prevent the movement of fish to complete their life cycles and concentrate fish into areas where they can be over-exploited. The cumulative impact of these barriers on the Lower Mekong Basin fish populations is large and has long term implications for the continued productivity of this system.

The rehabilitation of fish passage at these barriers is a high priority and can be achieved through the construction of suitable fishways. Fishways are devices that allow fish to pass a barrier by creating a series of small steps, or by slowing the velocity of water to one that can be easily negotiated by the fish. The construction of a fishway at a barrier is a significant undertaking and needs to be done at high priority sites first and with designs that are suitable for each barrier.

This document sets out a process for practitioners that allows them to identify the most high priority barriers for repair and undertake a design and construction process that will lead to high quality outcomes for fish passage. The process handles the large number of barriers present within each system by using remote sensing tools and analysis to identify and rank barriers. Based on physical, biological and socio-economic considerations the process prioritises which barriers should be targeted for rehabilitating and restoration of fish passage. This prioritisation process has been successfully used in the Xe Champhone catchment of the LMB as well in sub-tropical and tropical river systems overseas. The document then sets out a design and construction process for fishways that will guide practitioners through the selection of a design team and determination of the best fish passage solution for each of the high priority barriers. No one fishway design will fit all sites, so to achieve effective fish passage a design team that has appropriate biological and engineering expertise as well as operator input is vital. The combination of biological, engineering and structure expertise is key for successful implementation of fish passage. These guidelines therefore provide practitioners with the tools required to see through any fish passage project to a successful conclusion.

Introduction

The Lower Mekong River System is the most important aquatic ecosystem in South East Asia, with extremely high fish diversity levels and habitat complexity. It supports the health and wellbeing of 60 million people, who rely on the supply of fish and other aquatic animals as their major source of animal protein and cash income (Hortle, 2007; Baran & Ratner, 2007). Significantly, the population in the Lower Mekong Basin (LMB) is predicted to double by 2030 (Osbourne, 2009), placing immense strain on natural resources within the catchment (Baran et al., 2007). Sverdrup-Jensen (2002) warned the demand for capture fisheries in the LMB is expected to increase by 20 percent over the next 10 years alone.

Modification to the landscape to improve agricultural production and protect communities from flooding has occurred over the last 20 years and continues today. There are literally tens of thousands of structures that can affect to fish migrations in the LMB (Figure 1). The scale of river development is expected to have negative impacts on LMB fisheries. One of the main negative impacts has resulted from the construction of instream structures such as dams, weirs, regulators and floodgates which create barriers to fish migration. These barriers limit the migration of fish species, affecting the successful completion of life cycles and leading to over-harvest where local communities exploit fish accumulations below the instream structures.

This guideline document outlines a step-by-step method for the identification and prioritisation of all existing barriers to fish migrations. It also offers advice on the steps required to design, construct and maintain fish passage and how to monitor the effectiveness of these structures to pass fish, be they large or small. The aim of this guideline is to provide a process to ameliorate the impacts of barriers on fish migrations so that informed investments in effective barrier rehabilitation and operation can be undertaken by NGO's and government organisations. The guideline does not provide guidance on providing passage at other structures such as channels, pumps and other headwork structures which are not considered part of the natural stream system.

It is anticipated that through the implementation of this guideline that there will be a clear improvement in the productivity of each of the receiving systems. How much this improvement is will vary with the relative impact that the barrier is currently having on the system, however, the guideline will guide practitioners towards the structures that will have the greatest chance for improving productivity if passage is restored.

Barrier Prioritisation

The prioritisation process used in this guideline has been successfully trialled in two smaller catchments of the Lower Mekong, the Xe Champhone and the Nam Ngum. The trials have demonstrated that the prioritisation process can be undertaken successfully in the LMB and it is suitable for implementation in other sub-catchments throughout the basin. The suggested design and construction process has been used successfully in the implementation of fish passage rehabilitation in Australia and more recently at the Pak Peung regulator in central Lao P.D.R.

The barrier prioritisation process suggested for this study was developed to ensure that where information and resources are limited, they are efficiently utilised to identify barriers having the greatest impact on fish migration. It is a derivative of the Scoring and Ranking Technique used throughout Europe, the USA and Australia, but includes broad concepts derived from the optimisation techniques used in highly developed countries. In this way it can keep the simplicity of the scoring and ranking system, but use the re-evaluation power of the optimisation system.

The process also takes into consideration limitations on the available information for each of the catchments. As such the GIS data used to assess the priority of a barrier often uses proxy information that is available to provide information about aspects of biology that are not directly available. For example there is limited information available about the condition of the fish community in each and every stream as this information is difficult to collect. However many studies have demonstrated the link between habitat condition and fish community condition, with highly degraded habitats having reduced fish communities. The degradation of habitats is directly related to the intensity of landuse in the surrounding catchment, which can be easily identified by landuse types in a GIS. Thus the intensity of landuse can be used as a substitute for the condition of the fish communities, with fish community condition in pristine undisturbed catchments highly likely to be better than those in intensively developed catchments. In this way mapping characteristics that are available and can be assessed by the GIS can stand in for characteristics that are difficult to collect and represent spatially.

The prioritisation is run over a comprehensive five stage process that identifies barriers (Figure 1) and evaluates the fishery and ecosystem improvement, economic cost and social benefit of barrier repair. These five stages include:

a) Identification – using available information and satellite imagery

b) Remote Assessment – GIS analysis of five attributes of the potential barrier

c) Field Appraisal – record physical attributes of high priority potential barriers

d) Biological Assessment – GIS analysis of five properties of the barrier and site

e) Socio-economic Assessment – consideration of four socio-economic factors

Thousands of potential barriers can be assessed prior to requiring site visits. An initial desktop study employs the efficiency and unique decision making capabilities of an automated GIS system to assess wide-ranging temporal and spatial habitat characteristics associated with each potential barrier. The approach allows limited resources to be directed towards assessing the highest ranking potential barriers after the initial GIS stage, rather than a more arbitrary approach of visiting unknown and often less critical barriers based on limited local knowledge.

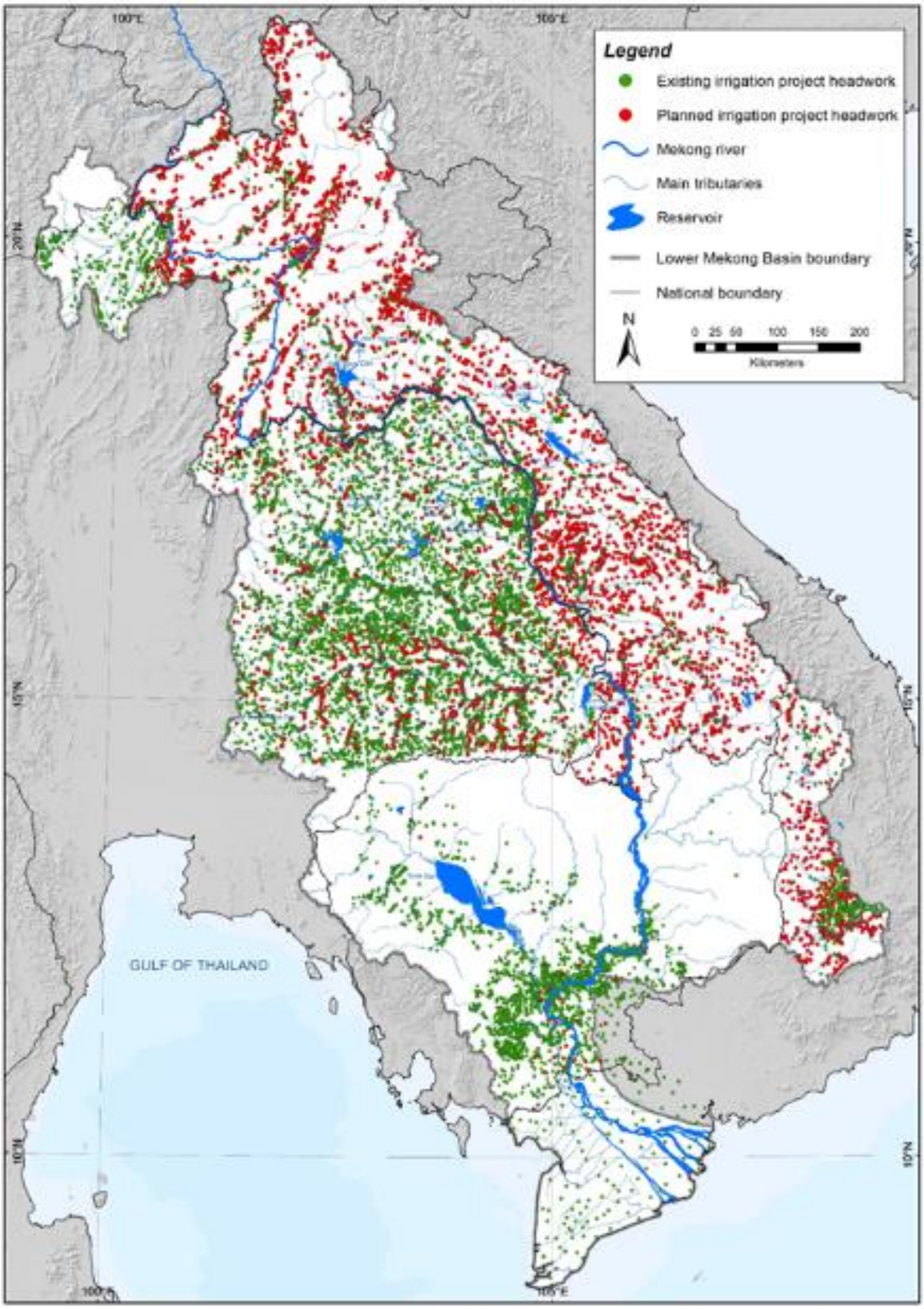


Figure 1. Location of irrigation infrastructure in the lower Mekong Basin.

The focus of this prioritisation is on identifying barriers to migration impacting the entire fish community. This is different to assessment criteria of other barrier prioritisations that are biased towards particular fish families, economically important fish species or specific river reaches (Kemp & O'Hanley, 2010). Subjective prioritisations, particularly those focused on primarily high value species, inadvertently create environmental conditions unsuitable for some sections of the fish community, either by upsetting the balance of predator to prey relationships or by disadvantaging fish species that occupy specialised trophic niches fundamental to aquatic ecosystem functioning (Kemp & O'Hanley, 2010). Barrier prioritisations that only investigate particular river reaches or sub-sections of catchments also have the potential to neglect or inadequately investigate downstream barriers (Moore and Marsden 2008). This is particularly pertinent as a single downstream barrier may be preventing or delaying sections of the fish community from reaching upstream habitats.

Barrier Assessment Procedure

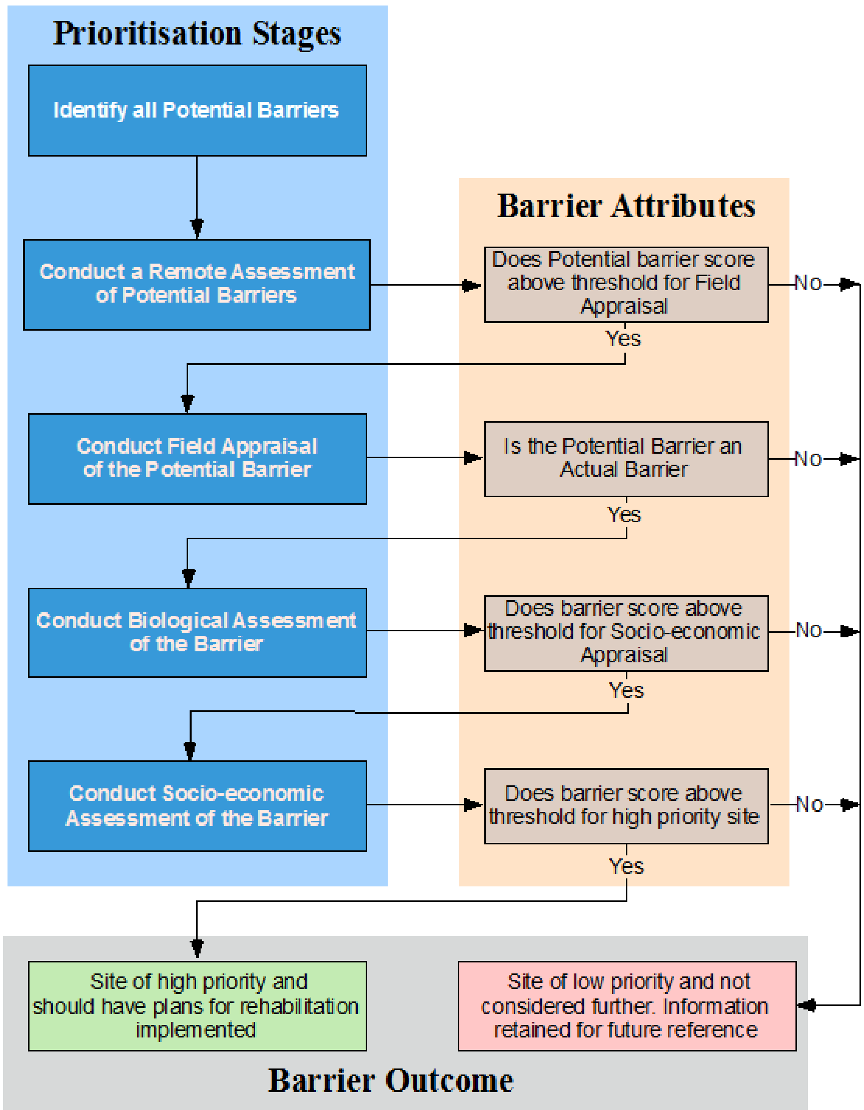


Figure 2. Flow chart representing the various stages of the prioritisation process.

The score and rank system utilises the five stages of assessment in conjunction with an automated GIS process (Figure 2). The system takes into consideration the importance of various migration patterns and the likelihood of localised extinctions caused by the barrier. As a result the process is designed to favour barriers located close to the Mekong River or the South China Sea. Barriers located close to these areas will affect a greater number of species by preventing fish from migrating upstream to feed or breed. A large portion of recruits to a population can be lost if adults cannot find suitable spawning habitat and juveniles are unable to find suitable nursery habitats. If fish passage is prevented year after year, fish populations can be severely diminished and over time lead to localised species extinction (Larinier 2001). The impact of barriers on the large fish communities close to the Mekong River or South China Sea is considered to be more critical than their effect on the smaller fish communities in the headwater streams. Additionally these headwater streams have much greater gradients that can create natural barriers to fish movement.

Adjustment of Scores or Weighting of Attributes

As individual regions will have different priorities for the rehabilitation of fish passage, as well as unique conditions that may bias the results of the prioritisation process, the adjustment and/or weighting of scores may be appropriate. This guideline has outlined a scoring regime that is suitable across most of the Mekong Basin, however, individual countries or regions may need to score some attributes differently.

An example where the adjustment of scores may be appropriate can be found in the two section of the Mekong Basin found in Vietnam. In the upper reaches of the Vietnamese Mekong many of the structures are very large due to the steep gorges of the streams in the area, while in the delta section of the Mekong River barriers are unlikely to be very large as the country is very flat. In this example the small barriers are likely to block large migrations just as effectively as a high barrier and should therefore be scored similarly. In this case the score can be adjusted so that smaller barriers score that same as large barriers.

An example of where the weighting of attributes might be appropriate would be where a regional committee believes that the productive benefit to local villages should be the highest priority within the scoring system. As such the committee may determine that proving a 100% weighting to the Productive Benefit score (thereby doubling the score) will ensure that this aspect is given the correct consideration within the scoring system. In this way the committee can ensure that projects with the most benefit to the local community will be considered the highest priority.

The adjustment of scores or the weighting of different attributes can allow the local project officers to refine the priority list to reflect the unique circumstances that occur in their local area, or are of concern to their local communities. However it should be recognised that overuse of the score adjustment or attribute weighting can have a detrimental impact of where rehabilitation works are undertaken and as such should be used sparingly and with caution.

Rehabilitation

These guidelines also recommend a process for implementing the design and construction of fish passage at a priority barrier. The fishway design and construction is a particularly important stage in the rehabilitation process, as any mistakes made in this step will lead to the installation of ineffective fish passage. Any design or construction errors are extremely hard to rectify in situ and can derail support for further fish passage infrastructure. It is therefore important to get the design and construction process correct to ensure long-term and effective fish passage at priority sites.

The ongoing operation and maintenance of any fishway constructed on a barrier is also a significant factor in the success of the fishway. Fishways that are not maintained or are operated incorrectly are also likely to lead to ineffective fish passage at a site. Installing and implementing the correct procedures and plans as outlined, after the completion of construction is therefore vital to the long-term operation of the fishway.

To determine if all of the preceding steps have been undertaken successfully requires the monitoring of the use of the fishway by fish. It is surprising how many projects assume that their constructions are successful and fail to conduct any monitoring of the fishes' use of the structure. To truly determine if a fishway has increased the fisheries productivity of a system requires a rigorous monitoring program that looks to assess the performance of the fishway and how it is impacting on the fish communities of the surrounding catchment. This guide provides options for detecting the success of any fish passage installation that can be tailored to the scale of the project.

This guideline is a comprehensive manual for the prioritisation and implementation of fish passage rehabilitation that is applicable to the LMB. The prioritisation methodology can be applied successfully across large numbers of barriers and allows for variation in input data and scale of structures. The level of detail for the fishway design and implementation processes can be scaled up or down depending on the type of barrier and by using a multi-disciplinary design team. The approach has already been successfully trialled in the Xe Champhone catchment in the LMB see Appendix 1.

Step1 - Locating Potential Barriers to Migration

The first stage of the process requires the identification of all fish migration barriers to include in the barrier prioritisation. It is critical that all barriers are included at this stage as any barrier not included may render provision of fish passage at other barriers useless. To this end the prioritisation process aims to identify each and every structure that could potentially impact fish passage within a catchment, even if at a later stage it is proven to not be a barrier. These potential barriers are all included in the analysis process during the initial stages to allow a refined list to be created for the field assessment stage for a more efficient use of on-ground resources.

What is a Fish Migration Barrier

A fish migration barrier is any structure that crosses a fish migration pathway along rivers and streams and into wetlands. These barriers can take many forms and impact on fish communities in a variety of ways. Large barriers such as dams and weirs create a vertical drop that fish are not able to jump, while lower barriers like culverts and regulators create high velocities which fish cannot swim against. The main structure types impacting on migrations include:

Fixed Crest Weirs

Fixed crest weirs are defined as a low dam or wall built across a stream to raise the upstream water level. During the wet season unregulated flow is discharged over the crest, while during the dry season the weir holds back stored water for use by local communities. A wide variety of weirs have been constructed throughout the LMB, with most located in streams and rivers. They generally consist of a fixed crest structure that stores water for delivery off-stream via irrigation canals (Figure 3). Some weirs are also constructed at the outlet of wetlands. In association with bund walls these structures usually increase the storage area of the wetland from its natural state (Figure 4). Fixed crest weirs are generally considered to be partial barriers to fish migration, depending on their height and drown out characteristics. If they are high and drown out infrequently their impacts on fish communities can be very large. However low structures that are easily drowned out by flood flows may have only a minor impact on fish communities.

Figure 3. Typical run of the river weir located on an upland stream that is too high for fish to ascend.

Figure 4. Weir on the outlet to a wetland complex in the Xe Champhone catchment.

Gated Weirs

Gated weirs do not have a fixed crest but instead have a series of gates that can be raised or lowered to store water upstream. Flow is usually discharged under the gates, with the gates raised during high flows so as to not get damaged and lowered during lower flows to hold water upstream. The gates are then operated during low flows to provide water to downstream consumers. Gates may be radial (Figure 5) or vertical (Figure 6, with radial gates preferred on the larger structures. Gated weirs generally have high velocities under the gates that can negatively impact the movement of fish in both an upstream and downstream direction.

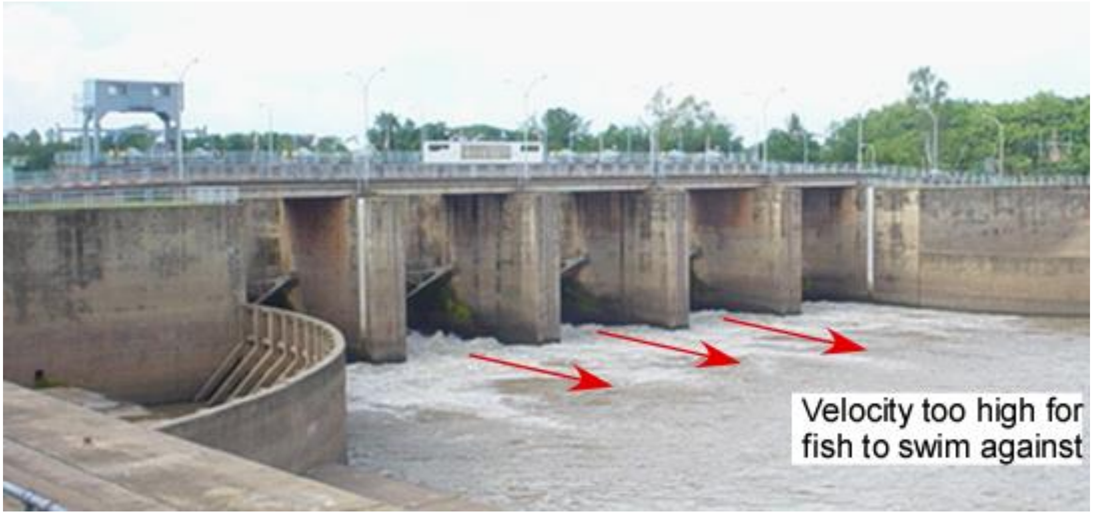


Figure 5. Radial Gated Weir located on a major river has high velocity that fish cannot swim against.

Figure 6. Small gated weir located on a minor tributary near Savannakhet (Laos).

Dams

Dams are bigger structures which create an extensive reservoir to supply water for hydroelectricity, for flood mitigation, potable water or to provide permanent water for irrigation schemes. They are generally greater than 10m high. A significant number of reservoirs have been built in the LMB, usually higher up in the catchment, where they are used to deliver water to the downstream irrigation area via irrigation canals (Figure 7) or to generate electricity (Figure 8). Dams form impassable barriers to fish migrations unless they have a fish transfer device installed because they are never drowned out by river flows.

Figure 7. Large irrigation dam located in the upper Xe Champhone catchment.

Figure 8. Large dam constructed to provide hydroelectricity.

Regulators

A regulator is a type of impounding structure able to release water downstream through the use of gates. These are similar to gated weirs, but are generally smaller and not primarily maintained to create a storage. Regulators are operated either to alter downstream discharge, or to manipulate upstream water level to gravitate water into irrigation systems. Regulators can also be used to store water for dry season needs. These systems may be located downstream of a weir, or off-stream. The gate structures range from complex steel lift gates, occasionally motorised, to simple drop board structures. A wide variety of regulators have been constructed throughout the LMB and are one of the most common types of irrigation structures affecting fish passage (Figure 9 and Figure 10). The high water velocities at the gates can negatively impact the movement of fish in both an upstream and downstream direction.

Figure 9. Steel regulator gates controlling water on a wetland outlet.

Figure 10. Another steel regulator gate controlling water from a wetland.

Flood Gates

Elevated water levels in the Mekong River and other major tributaries during the wet season can threaten floodplain rice crops. To protect floodplain infrastructure and agriculture, floodgate structures have been constructed in the lower reaches of many river systems. The floodgates aim to protect floodplain areas from excessive inundation when river levels exceed critical heights of rice fields. These structures consist of culverts set into levee banks along the river, usually at floodplain drainage points such as stream or wetland outlets (Figure 11). They have a series of flap gates that are forced closed if the water level downstream is greater than upstream. This prevents river water flooding onto the floodplain when there is limited local rainfall. The floodgate systems are common in areas that are affected by the Mekong River or other major tributaries such as the Nam Ngum. They form partial barriers for the most part of the year, but are complete barriers when they are closed, which often coincides with significant fish migration periods.

Figure 11. Floodgates on the outlet to wetlands in the Xe Bang Fei system.

Bridges

Bridges are not generally considered to be a barrier to fish migrations if they maintain the original cross section of the stream beneath them. However during their construction many bridges have further structures such as weirs and regulators built beneath them. These structures become the barrier to migration, so while bridges rarely are barriers it is important to record their presence from the imagery as they can conceal other barriers beneath them (Figure 12).

Figure 12. A weir hidden beneath a bridge.

How to Locate Barriers

To identify potential barriers, satellite imagery and aerial photography is analysed for each of the target catchments, identifying any structure that intersects a waterway and appears to create a barrier (Figure 13). This is corroborated with any secondary vector data available that identifies structures likely to be a barrier such as irrigation infrastructure or road crossing data layers. From this information, a potential barrier waypoint is created for each and every potential barrier and assigned a unique geo-referenced identification number that remains with the barrier throughout the five stage prioritisation process.

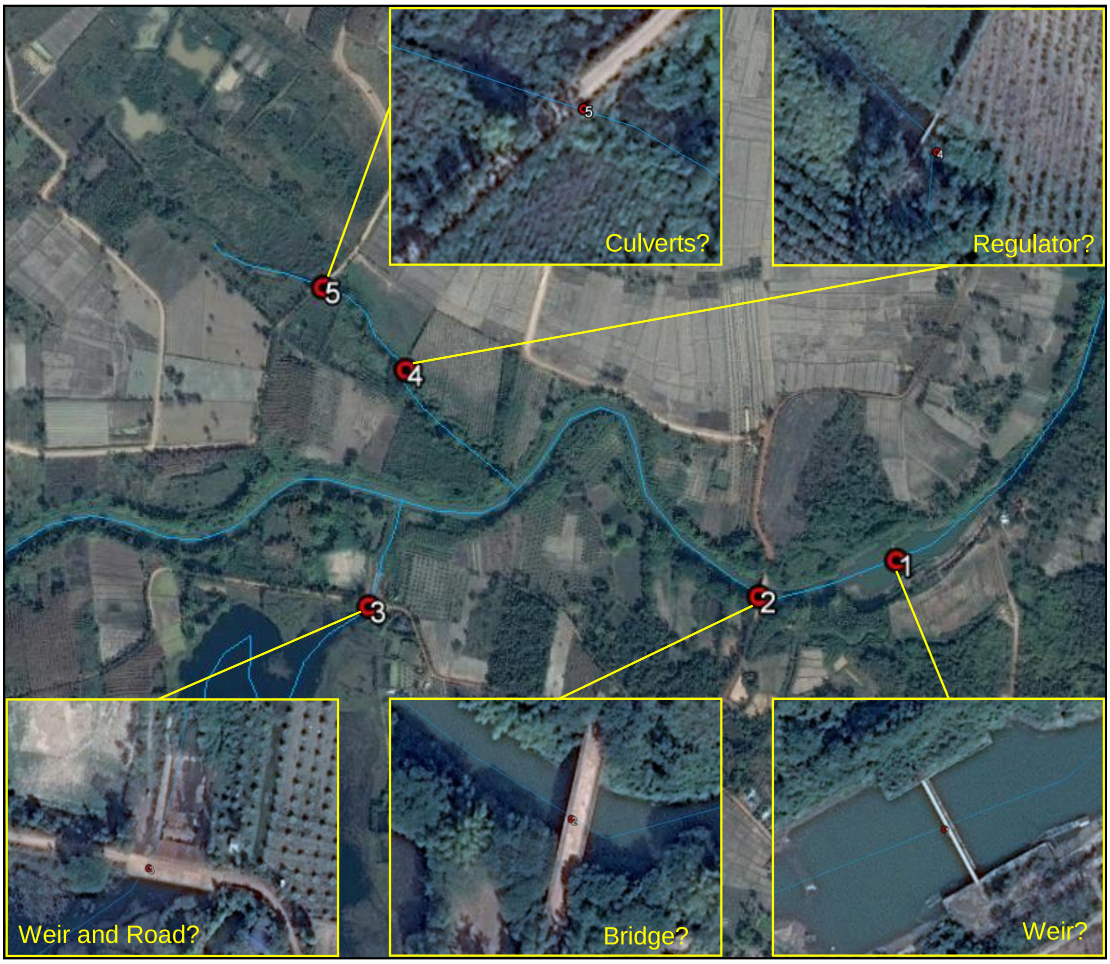


Figure 13. Potential barriers identified from remote imagery and other GIS sources.

Once all potential barriers have been identified, they are given an intial prioritisation using the second stage remote assessment that prioritises their rank in the catchment regardless of the type of barrier (or non-barrier) they are.

Step 2 – Conduct Remote Assessment of Barrier Priority

Stage 2 of the barrier prioritisation incorporates a desktop GIS process to efficiently investigate spatial and temporal habitat characteristics associated with each potential barrier identified in stage 1, without the need to visit the site.

This initial GIS process allows the prioritisation to set an achievable target of potential barriers for field appraisal in stage 3 of the process. The availability of resources typically determines the size of this inventory; if resources are unlimited then all potential barriers could be ground-truthed. However, due to the large size, sparse population, high numbers of barriers and limited funding available for fisheries-based riverine restoration projects, this is rarely achievable. Therefore the ability of GIS to rapidly assess large amounts of geospatial vector data for each potential barrier and produce a list of the top ranked barriers after stage 2 is invaluable.

Identified potential barriers are assessed against five geospatial questions relating to the barrier's position in the catchment, type and amount of available upstream habitat, size of stream (stream network or stream order) and number of barriers downstream. Each potential barrier is assigned a score (i.e. 1 - 10) depending on how the criteria was met for each of the geospatial questions. Scores for all questions are combined and totalled and the final rank after stage 2 determined, i.e. highest total score becoming the highest ranking barrier in stage 2.

The following attributes will determine if a potential in-stream barrier is a high priority after stage 2 of the selection criteria process:

a. Barrier located in the lower reaches of the river system – as barriers have the greatest impact on upstream movement and the large habitats of the Mekong or South China Sea contain the most fish, barrier close to these sources will have the largest impact on fish communities;

b. Located on a large river or wetland – large rivers provide the best and most diverse habitats, maintain refuge pools throughout the dry season and have the most diverse fish communities, so barriers on these rivers are likely to have a greater impact on a larger range of species;

c. Minimal to no barriers located downstream – barriers downstream of a site restrict the movement of fish up to the site. As it always harder for fish to move upstream past a barrier, having many barriers downstream reduces the number of fish that can make it to a site, making the downstream barriers more critical;

d. Good catchment condition – fish communities in catchments with minimal adverse surrounding landuse practices are generally in better condition than those that are negatively affected by pollution from the surrounding land;

e. Large area of available upstream habitat – the amount of habitat opened up above the barrier to the next barrier or top of catchment if the barrier is repaired must be large, otherwise there is limited benefit to the repair. The more habitat that is opened up by the barrier the better it is for the fish community.

Each of these attributes will be categorised by the project team and a score attributed. The scores for each attribute is weighted by the importance of that attribute in determining the priority of the barrier.

Biological assessment selection criteria attributes

Attribute 1. - Stream Type

The first attribute to be assessed is the type of waterbody the potential barrier is located on i.e. major river/wetland, medium river/wetland and small stream/wetland. The associated surface water hydrology classification (permanent or intermittent) is also considered. Permanent major river/wetland scores the highest, followed by permanent medium river/wetland. Small intermittent stream/wetland scores the lowest. Barriers located on small ephemeral waterways with a stream order of one are deleted from the process (Figure 14).

Stream/wetland size is powerful habitat proxy. Large streams/wetlands generally contain a greater complexity of habitats, higher diversity and abundance of fish species and larger additional subsistence and economically profitable fish species than small streams/wetlands (ICUN 2011).

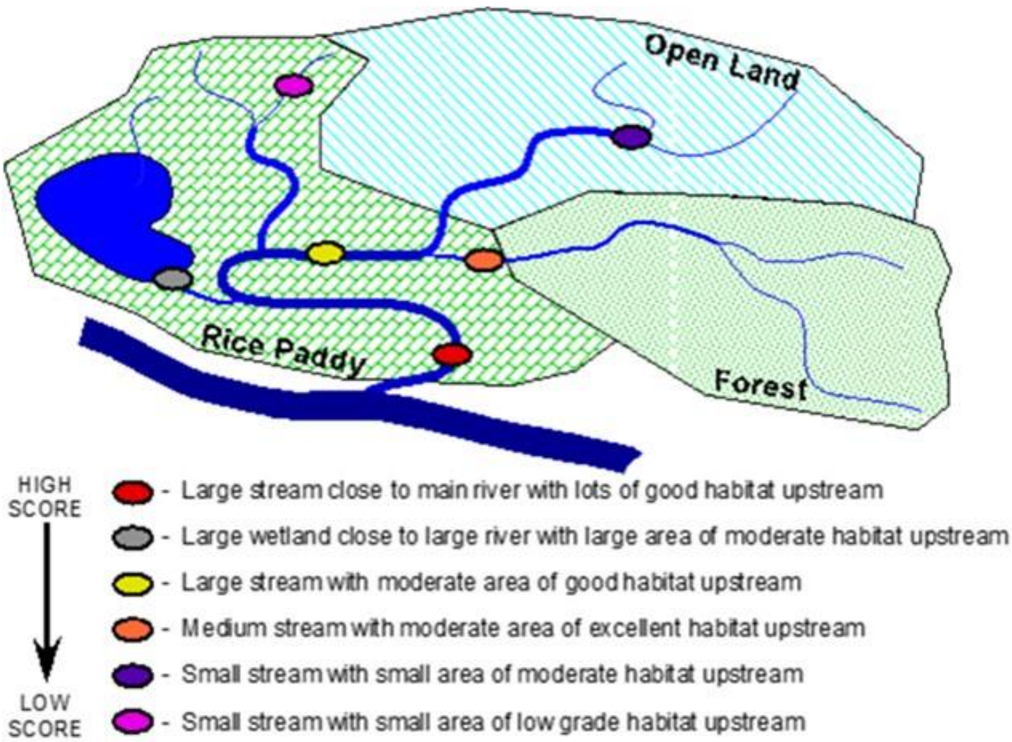


Figure 14. Scoring of various stream types in a typical catchment.

Table 1. Scores attributed to stream type for all potential barriers

Waterbody Category	Score
a. Permanent major river/Wetland ≥ 400 hectares	10
b. Permanent medium river or stream/Wetland 30 – 399 h	7
c. Intermittent small stream/Wetland 1 – 30 h	2
d. Small ephemeral stream order one	*Removed from process*

Attribute 2 – Intensity of Landuse

This attribute is determined by the percentage (%) of intensive landuse within the sub-catchment the barrier is located in. Using ArcMap, landuse data is clipped to the sub-catchment. Intensive landuse practices are then grouped together and total intensive landuse calculated. Intensive landuse categories include: rice, agricultural plantation, other agricultural land and urban or built up area. The intensity of agriculture directly affects the fish communities within a river system, as there are many negative effects on the fish habitats within the system. The clearing of the land and the riparian zone often leads to high levels of sediments within the system that smothers habitats and reduces refuge pool size (Figure 15). These impacts negatively affect the fisheries of the catchment, reducing catches to local communities. As such sub-catchments with minimal intensive landuse can produce more fish and score higher in this attribute scoring.

Figure 15. Pristine catchments have better fish communities than those surrounded by intensive agriculture

Table 2. Scores to be attributed to the catchment condition for all potential barriers

Catchment Condition	Score
a. 1 - 1.9% intensive landuse	5
b. 2 – 9.9% intensive landuse	4
c. 10 – 24.9 % intensive landuse	3
d. 25 – 34.9% intensive landuse	2
e. ≥ 35 % intensive landuse	1

Attribute 3 - Upstream Habitat (waterbody area in hectares)

This step looks at the waterbody area (ha) opened up by the repair, upstream of the barrier to the next barrier or top of catchment. If it is the uppermost barrier (there must be barriers downstream) then 2 points are taken off the score to balance the area available upstream of the last barrier (lowest score possible is 0).

To calculate upstream waterbody area, each stream category is assigned an average width. Average widths are based on the average width of each stream category. Permanent major rivers are calculated to have an average width of 100 meters, permanent medium rivers an average width of 12 meters and intermittent small streams an average width of 4 meters. Total length of stream upstream from the potential barrier to the next barrier or top of catchment is then calculated in ArcMap. Stream length is then multiplied by the average width to determine the area in square kilometres. Which is then converted into hectares. Area of upstream habitat for a wetland barrier is determined by calculating the area of the wetland plus the area of any tributaries flowing into the wetland until the top of the catchment or next barrier. Barriers with larger areas of available upstream habitats received a higher score (Figure 16).

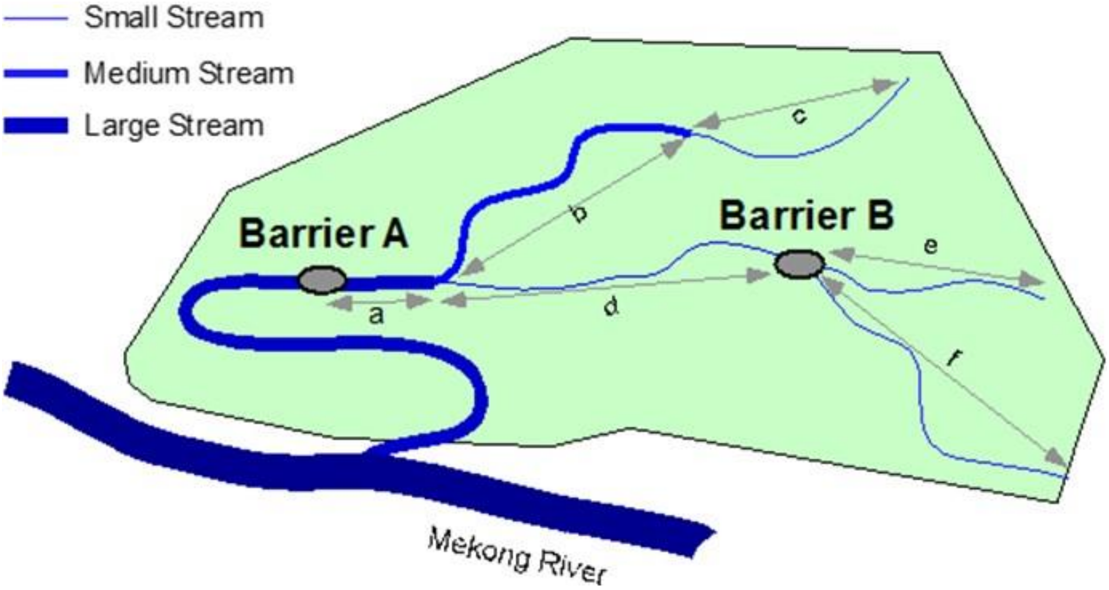


Figure 16. The sum of the area of habitat upstream of Barrier "A" is larger than that of Barrier "B", therefore Barrier "A" receives a higher score.

Table 3. Scores to be attributed to the upstream habitat area for all potential barriers

Waterbody Area Upstream (hectares)	Score
a. ≥ 500	5
b. 200 - 499	4
c. 100 - 199	3
d. 10 - 99	2
e. 0 - 9	1

Attribute 4 - Number of Barriers Downstream

This step assesses the number of potential barriers downstream of the barrier being assessed. That is the total number of potential barriers downstream in a direct path to the confluence with the Mekong River (or South China Sea if the barriers is on the Mekong River). The main impact on fish movement is blocking the upstream movement of fish and as such a barrier that has many barriers downstream from it will have a lesser number of fish being able to access it and therefore be of a lower priority than those that have few barriers downstream (Figure 17).

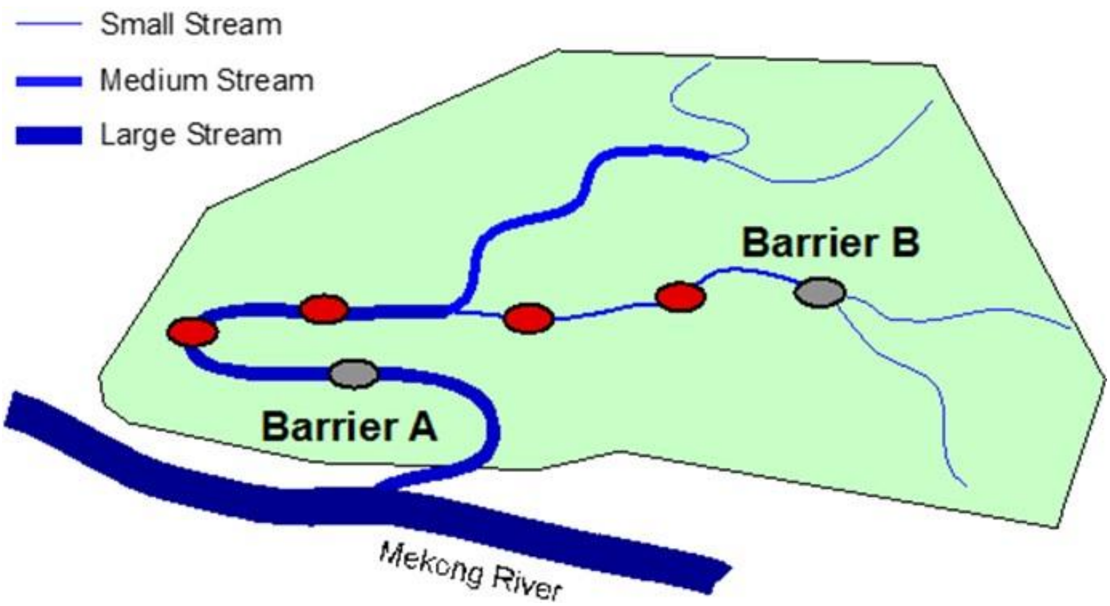


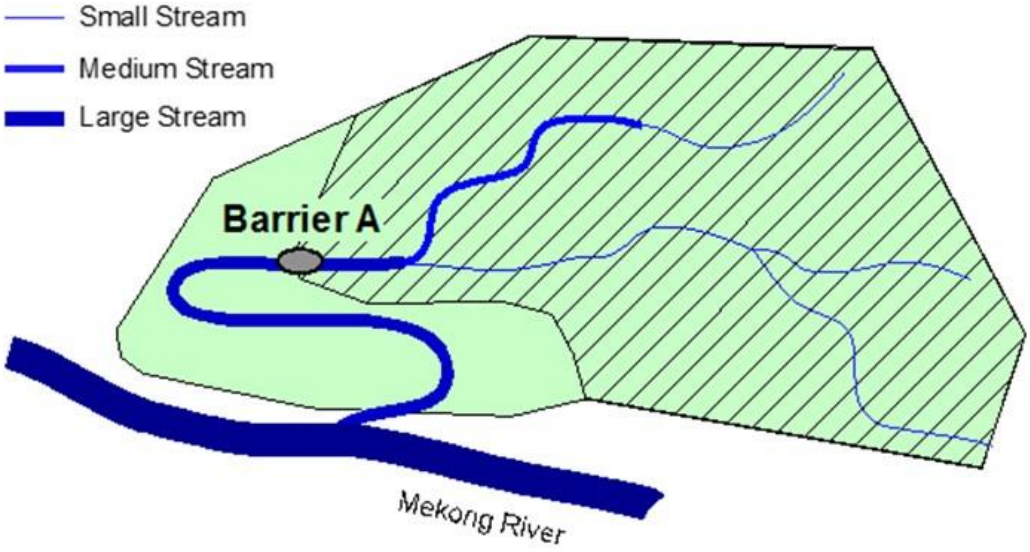
Figure 17. Barrier "A" has a higher score as it does not have barriers downstream that restrict passage to the site, whereas Barrier "B" has several barriers downstream that need to be rehabilitated before fish can get to the site.

Table 4. Scores to be attributed to the number of barriers downstream for all potential barriers

Total Number of Barriers Downstream	Score
a. No potential barriers downstream	7
b. One potential barrier downstream	5
c. Two to four potential barriers downstream	3
d. Five to nine potential barriers downstream	2
e. Ten or more potential barriers downstream	1

Attribute 5 - Sub-Catchment Characteristics

This step of the process assesses the waterbody area (ha) upstream of the potential barrier as a proportion (%) of the total waterbody area (ha) within the *entire* catchment. Barriers that are blocking a high proportion of the catchment have a greater impact than those that only block small section of the catchment. As such potential barriers that are at the lower end of a catchment will score higher than those in the upper reaches. Stream area (ha) upstream of the potential barrier includes all tributary streams above the location of the potential barrier to the top of the catchment (Figure 18).



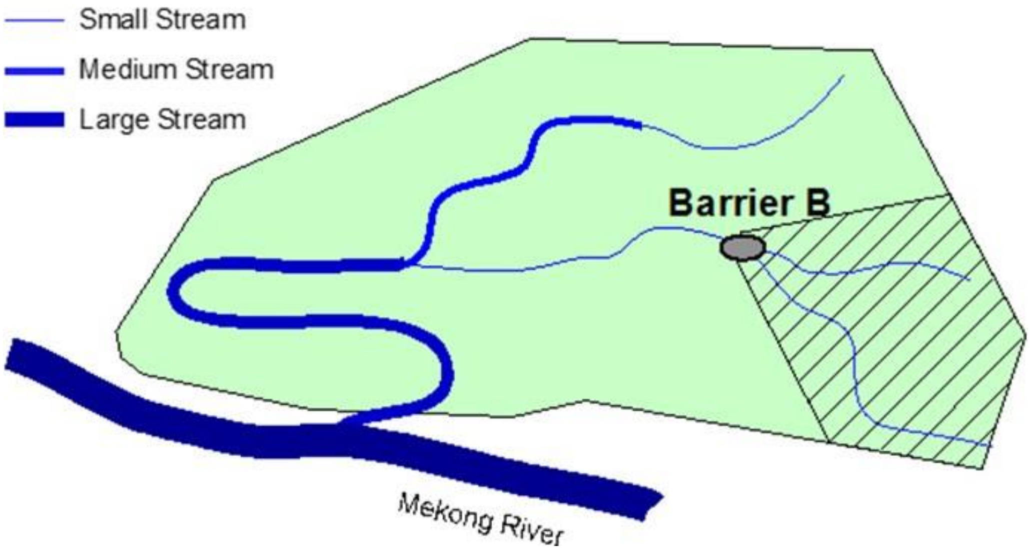


Figure 18. The percentage of barrier upstream of Barrier "A" is larger than that of Barrier "B", therefore Barrier "A" will score a higher score.

Table 5. Scores to be attributed to the percentage of the catchment upstream of the potential barrier

Area of upstream habitat as a proportion of entire catchment		Score
a. 50+ %	of total catchment	7
b. 30 – 49 %	of total catchment	5
c. 10 – 29 %	of total catchment	3
d. 5 – 9 %	of total catchment	2
e. ≤ 4 %	of total catchment	1

The utilisation of GIS to assess the first 5 attributes of each of the potential barriers enables the prioritisation process to assess tens of thousands of potential barriers and systematically rank them. This step is critical to the method’s success, as it identifies and analyses every potential barrier before directing on-ground resources towards visiting the most important of these potential barriers. These priority barriers are locatable on the Potential Barriers Database this software, combined with mapping software will guide the field truthing in the next stage.

Step 3 – Conduct Field Appraisal of Highest Priority Potential Barriers

Stage 3 of the prioritisation process involves undertaking field appraisals of the highest ranked potential barriers after the remote assessment. This will determine if the site is an actual barrier and also define the actual characteristics of the barrier that cannot be determined remotely (Figure 19). Non barriers (ie those determined to have no impact on fish passage at any stage of the hydrograph) are immediately removed from the assessment process as they have no impact on fish communities.

Figure 19. Two potential barriers identified in stage 1 are visited. A is a bridge and not a barrier, while B is determined to be an actual barrier and further measurements taken.

The scope of the initial ground-truthing inventory will be determined by the available staff resources to visit the sites and physically record data about the potential barrier. Around 200 sites is an achievable number of sites for a small team to visit in a month long period and will derive a large enough list of sites to support rehabilitation efforts for a number of years in a region. If the resources are available, larger field appraisals can be conducted by scaling up the number of staff for each area.

To undertake the field appraisal a team of fisheries biologists, engineers and local irrigation officials should be assembled. This mix of expertise allows all factors associated with the barrier to be understood and enables the most comprehensive list of data to be collected. The field team will utilise a variety of tools to find and assess each of the potential barriers. The barriers should be pinpointed on portable mapping software that can be taken to site with the team. Utilising tablet computers loaded with mapping software is the most efficient means by which to navigate to the site. Relying on local knowledge is useful, but also limited as many barriers are old and unused and it is essential that teams identify the correct barrier i. Local knowledge should be used as an adjunct to the mapping and at no stage should replace the GIS mapping tools, as this can compromise the data collection process. Tools that will prove useful for the team to locate, identify, measure and record data from the site include:

- Car/van and driver;
- Tablet computer installed with GIS mapping/navigation software with Potential Barriers Database;
- Laser level or other accurate height measuring tool capable of measuring the relative height of objects across the entire site;
- Digital camera and/or video
- Tape measures of sufficient length to measure entire site (laser measures are useful at large sites)
- Data sheets and recording tools

Once onsite, field teams record a variety of attributes of the barrier that will input into the stage 4 and 5 Biological and Socio-economic assessments. Important barrier information to be gathered includes;

- Barrier dimensions – all relevant dimensions that will inform the later stages of the prioritisation and help with determining suitable fish passage options;
- Headwater and tailwater levels and variation – critical for determining fish passage options and if/when the structure drowns out and passes fish;
- Observed fish species - to determine whether this is an important site for the local community and if passage past the site critical for local fish species;
- Structure owners – owner/operators will need to be consulted on what, if any, repairs will be acceptable at the site given the current usage of the structure;
- Importance to the community – whether the site an important fishing resource to the community;
- Village interest/support – does the local community recognise that this site is a barrier and that providing fish passage would be good for their community;
- Access for heavy machinery – if rehabilitation were to take place, is the site readily accessible for work crews to easily access.
- Additional information such as the assessor's name, date of assessment, photos and video details, stream and barrier name, date and coordinates of the barrier are also recorded. Detailed site assessment sheets have been created that allow accurate recording of the data from each site (Figure 20).

Barrier Ref No:__________ **Stream Name:**____________________

Barrier Name____________ **GPS Location: Lat**________ **Lon**________

Video- File Name ____________ **Photo File No.** ____________

Barrier Description		Weir/Dam/ Road Crossing	Culvert	Pipe	Sluice Gate
Height	Entire Structure				
	Individual Culvert/Pipe				
Width	Entire Structure				
	Individual Culvert/Pipe				
Length	Entire Structure				
	Individual Culvert/Pipe				
Number of Pipes/Culverts/Gates					

Water Level	Tailwater	Headwater
R.L Min (m)		
R.L Max (m)		

Apron Width (m)	
Apron Drop (mm)	

COMMENTS

Access to site for Construction - (excavator, backhoe, concrete truck/pump) ____________

____

Willingness of Naiban to modify structure________________

____

Fish Species Observed? - What are the fish species accumulating below barrier?

____

____

Questions

(Circle appropriate answer)

Barrier Type				
a.	**b.**	**c.**	**d.**	
Wetland Regulator ≥ 3 m high	Dam or Weir ≥ 3m or Wetland Regulator 1.5 - 3 m	Dam or Weir 1.5m – 3m or Wetland Regulator ≤ 1.5m or Culvert or Pipes ≤ 60% of stream width	Dam or Weir ≤ 1.5m high or culvert or pipes ≥ 60% of stream width	**No Barrier – DO NOT SCORE REMAINING**
Stream Condition				
a.	**b.**	**c**	**d.**	**e.**
Very Good (no apparent clearing of rip veg, bank degradation, etc	Good (≤ 25% of upstream areas degraded by clearing or bank degradation)	OK (25-50% of upstream areas degraded)	Poor (51-75% of upstream areas degraded)	Very Poor (≥ 75% of upstream areas degraded)
Water/Supply Quantity				
a.	**b.**	**c.**	**d.**	**e.**
Natural Permanent Flow	Dammed but Permanent Flow	Stream stops some years. Pools remain at all times	Stream stops every dry season but pools remain	Stream stops every dry season and there are no pools
In-Stream Habitat for Migratory Fish Species Upstream of Barrier Site				
a.	**b.**	**c.**	**d.**	**e.**
Very Good (Fish would do very well if they gained access)	Good (Fish would do well if they gained access)	OK (Fish would only do ok in this habitat).	Poor (Fish would do poorly in this habitat)	Very Poor (Fish could not live in this habitat)
Importance to Local Community of Fishing at Barrier				
a.	**b.**	**c.**	**d.**	**e.**
Most important fishing location (for village)	Regularly fish, second most important fishing location	Occasionally fish	Minimal fishing effort	Never fish

Comments ______________________________

____

Figure 20. Datasheets used in the prioritisation of the Xe Champhone catchment, Laos.

Step 4 – Conduct Refined Biophysical Assessment

The biophysical assessment stage scores the data collected from the field appraisal of the potential barriers and provides further refinement of the priority list created in the remote assessment stage. As the field appraisal discounted all non-barriers from the assessment, the biophysical assessment is now centred on confirmed barriers. This assessment identifies the highest priority barriers in terms of their effect on the biological productivity of a catchment.

Confirmed barriers are assessed against five physical attributes that affect biological productivity, relating to the barrier size, stream condition, water quality, instream habitat and fisheries production. Each barrier is assigned a score (i.e. 1 - 10) for each of the physical criteria.

The biological assessment assigns a score to all barriers based on 'how well' they meet the criteria for each of a further five questions:

a. Transparency of the barrier to migrating fish – barriers that are large and have a great impact on the movement of fish (not transparent) are in the greatest need of rehabilitation and will achieve a high score in this criteria. Low barriers that are often easily passed by fish have less impact, are scored lower and are a lower priority for repair;

b. Stream and riparian condition – barriers found in catchments with intact riparian zones are likely to have greater impact as the fish communities in these catchments are usually more productive than those in degraded catchments. To score highly in this criteria the catchment as observed by the assessor must be in good condition;

c. Stream flow – streams with natural, permanent and non-polluted flows have better fish communities than those where flow is restricted or polluted. Barriers on these more natural streams have a greater impact than those on more regulated streams. To score highly in this criteria streams should have good unpolluted flow as determined by the assessing team based on local knowledge;

d. In-stream habitat – streams with diverse and abundant instream habitats support better fish communities and barriers on such streams have a greater impact. To score highly in this criteria streams must have good instream habitats;

e. Importance of site to local fishers – streams with good fish populations are more popular and productive fishing grounds. If a barrier site is within an important fishing ground it is likely that any barrier in the stream would have a negative impact on fish communities and fisheries. Sites that are highly valued by fishers will score higher for this criteria.

Biological Assessment Selection Criteria Questions

Attribute 6. Can Fish Pass the Barrier

The size of the water drop over the barrier or the velocity of the water through a barrier reflects what proportion of the fish community is able to pass the barrier when migrating upstream. High barriers, such as dams without fishways, are not considered passable, even on large streams, as fish are not able to migrate upstream past them on any flows. Weirs have varying levels of passage depending on their height and the size of the stream they are built on. A low weir on a large stream has high passage levels as it will drown out more frequently than a large weir on a small stream which has low passage levels. The low weir allows greater upstream migration opportunities than the high dam (Figure 21). Culverts generally have more passage as fish can pass these barriers on all but the lowest of flows. To determine the score for this attribute, barriers are categorised by their size and type, with the higher barriers achieving a greater score, because their repair is more critical for fish movement.

Figure 21. Low culverts (left) have a much smaller impact on fish migrations than large dams (right) and score lower in the prioritisation.

Table 6. Scores to be attributed to the passage opportunity of the barrier.

Barrier type	Score
a. Wetland Regulator ≥ 3 m high	5
b. Dam or Weir ≥ 3m or Wetland Regulator 1.5 - 3 m	4
c. Dam or Weir 1.5m – 3m or Wetland Regulator ≤ 1.5m or Culvert or Pipes ≤60% of stream width	3
d. Dam or Weir ≤ 1.5m high or culvert or pipes ≥ 60% of stream width	2
e. No Barrier – DO NOT SCORE REMAINING CRITERIA	-

.

Attribute 7 – Stream Condition

The stream condition at the site is important for the fish community, as a healthy stream has greater numbers of fish than degraded streams. During a site inspection the team inspects the stream in the vicinity of the barrier and also investigates the condition of the catchment further afield with the assistance of the local community. The field team will be looking for conditions suitable for thriving fish communities, generally large deep pools and intact riparian vegetation. The condition of the riparian vegetation can often be used as a proxy for stream condition, as streams that have had extensive clearing of the riparian zone will have stream conditions that are degraded (Figure 22). This is due to the instability of the banks, the increase in sediment supply into the river and the smothering of instream habitats.

Figure 22. Large deep pools with good instream habitat (left) provide better habitat for fish than streams that have silted up and have minimal habitat (right).

Table 7. Scores to be attributed to the stream condition upstream of the barrier.

Stream condition	Score
a. Pristine-Undisturbed (no clearing of rip veg, bank alteration, etc)	5
b. Low Disturbance (≤ 25% of upstream areas altered)	4
c. Moderate Disturbance (25-50% of upstream areas altered)	3
d. High Disturbance (51-75% of upstream altered)	2
e. Very High Disturbance (≥ 75% of upstream altered)	1

Attribute 8 – Stream Flow and Waterhole Permanence.

Streams that maintain water flow and waterholes throughout the year have greater year-round carrying capacity and therefore greater long-term fisheries productivity than streams that dry up. This attribute identifies those sites with the greatest potential for high value fisheries and sites with year round good quality water will score higher. The field team uses local available flow data, or conducts interviews with local officials and the local community to determine the flow conditions that exist at the site and to identify if the stream flows all year round and at what intensity. If the stream ceases to flow, the team will try to establish the permanence of the waterholes that exist in the stream. Streams that dry up completely during the dry season provide no permanent habitat for fish and the productivity in these systems is considered to be less than those where fish can seek refuge over the wet season (Figure 23).

Figure 23. Permanent flowing streams (left) maintain fish habitats year round and have more productive fisheries than those that dry up (right) during the dry season.

Table 8. Scores to be attributed to the flow and permanence of the stream upstream of the barrier.

Water Supply/Quantity	Score
a. Un-regulated, permanent	5
b. Regulated Permanent (via supplemented flow)	4
c. Stream occasionally dries up with refuge pools	3
d. Stream dries seasonally with refuge pools	2
e. Stream dries seasonally with no refuge pools	1

Attribute 9 - Instream Habitat for Migratory Fish Species Upstream of Barrier Site

The presence of good quality instream habitat will improve the productivity of the fisheries in that stream. Weed beds, woody debris and riparian vegetation provide food and shelter for fish and improve the likelihood of there being healthy and productive fish communities. Field teams will be looking for streams that have high levels of instream habitat suitable for migratory fish species. Using their local knowledge and fisheries expertise the team determines what good habitat within that region is. Those streams that have high levels of intact habitats will score higher than those streams that have little or no habitat within them. Streams that have been maintained in good condition due good management or lack of development will generally provide the best habitats within this attribute (Figure 24).

Figure 24. Streams with limited instream habitat (left) will not score as high a score as streams that have diverse and abundant fish habitats.

Table 9. Scores to be attributed to the instream habitat of the stream upstream of the barrier.

Instream Habitat	Score
a. Excellent. Diverse and abundant in-stream fish habitat	5
b. Good. Reasonable amount of suitable in-stream fish habitat	4
c. Moderate amount of suitable in-stream fish habitat	3
d. Poor. Little suitable in-stream fish habitat	2
e. Very poor. Little or no suitable in-stream fish habitat	1

Attribute 10 - Importance to Local Community of Fishing at Barrier

The importance of a barrier to the local fishing community is intrinsically linked to the number of migrating fish being negatively affected by the barrier. Barriers with large numbers of fish stuck below (downstream of) them are more heavily fished than those barriers with few fish. This question identifies particular sites where reinstating fish passage could potentially significantly increase productivity in the waters upstream of the barrier. As most streams have little or no information on the migrations of their fish species, this metric is able to give an approximation of the negative impacts that the barrier is having on local fish communities. This provides an indication of where the rehabilitation of fish passage would have the greatest benefit to all the local communities, not just those located at the barrier. The field team would look for evidence of fishing activities at the barrier such as traps, nets or casting stands, as well as interviewing local villagers on the fishing activities that occur at the site (Figure 25) and the timing and intensity of migrations that are occurring at the site. Sites with high levels of fishing pressure score higher.

Figure 25. The intensity of fishing below a structure can indicate the importance of the site for the rehabilitation of fish passage.

Table 10. Scores to be attributed to the importance of the barrier to local fisherpersons.

Importance to Local Fishers	Score
a. Most important fishing location (for village)	5
b. Regularly fish, second most important fishing location	4
c. Occasionally fished	3
d. Minimal fishing effort	2
e. Never fished	1

Once scoring for all attributes has been collated, the scores for each barrier are totalled and added to the score for that barrier from Step 2, the remote assessment. The barrier with the highest combined score becomes the highest ranking barrier affecting the biology of the fish community. While the attributes in the next stage of the assessment process (socio-economic assessment) will determine the barriers most likely to be rehabilitated, it is very important that the ranking from this assessment is recognised separately. This assessment gives an indication of which barriers are affecting the life cycles of the fish community the most. It is these barriers that most impact fisheries productivity by limiting the movement of fish into the productive habitats upstream. Therefore it is these barriers which will provide the largest increase in fisheries productivity if they are rehabilitated. However, while increasing biological productivity is an essential outcome of the prioritisation process, the rehabilitation of barriers will be conducted by a wide range of organisations with a variety of agendas. The next stage of prioritisation takes into account these non-biological drivers for rehabilitation.

.

Step 5 – Conduct Socio-Economic Assessment of High Priority Barriers

The socio-economic assessment introduces a number of social and economic factors to further refine the prioritisation list. This step identifies the most cost-effective barrier for repair with the greatest benefit to the local community. While the previous stages of the prioritisation have identified which barriers have the greatest impact on the biology of the fish communities, this stage identifies non-biological factors and their impact. It is extremely important in determining whether the cost of construction is justified by the social and biological benefits the fishway will generate for both local community and the environment. In this stage the refined list of barriers from the biological assessment is further analysed. Like the other stages, barriers in the socio-economic assessment are assigned a score based on 'how well' they met each of the four selection criteria. A high score for the following attributes means the in-stream barrier scores well in the socio-economic assessment stage of the prioritisation process:

a. Repair cost – the lower the cost to remediate the barrier the more likely it is that the barrier will be rehabilitated. Generally smaller barriers with simple fish passage requirements will be cheaper to remediate than larger barriers with complex fish passage requirements, hence they will score higher than the more complex structures;

b. Fishway Design – a barrier that requires a simple fish passage design with minimal engineering will be easier to fund and complete with local expertise than a barrier requiring highly technical fishway designs to provide passage. As such barriers requiring simpler designs will score higher than more technical fishways;

c. Fish Passage Effectiveness – unless a barrier is completely removed, any repair will only provide partial passage for the fish community. Some fishway designs will provide better results than others, with full-width rock ramp fishways able to pass nearly all fish on all flows, while steep submerged orifice fishways only pass a small proportion of the fish attempting to migrate. If the barrier is suitable for a highly effective fishway design that can pass many fish it will score higher than those barriers where only sub-optimal designs can be implemented;

d. Fisheries Productivity Gains – the improvement in the productivity of fisheries is the primary aim of the rehabilitation of fisheries in the LMB. For repair to be effective it must provide productivity gains where they can be accessed by the local community. As such barriers that provide great productivity gains to many villages will be of a higher priority than those that do not benefit any villages.

A very important aspect of this third stage of the process is considering the net benefits of fixing the barrier versus the economic cost of the repair. As much of the fish passage repair works will be funded by government departments and NGOs whose funding capacity is often quite limited, this stage of the prioritisation is important in understanding which barrier can be affordably fixed in line with resources. Smaller structures are cheaper to construct and are often the most cost effective for the investor. A score is assigned to each answer and once all the barriers have been analysed, scores are collated for the socio-economic assessment.

Socio-economic Assessment Selection Criteria Questions

Attribute 11 – Estimated Cost of Construction

As funds for fishway construction are generally limited, it is important to ensure that the best value is achieved with each fishway. To ensure this, fishways that are lower in cost score higher points than those that are expensive to build. As such, two barriers with equal potential to increase fisheries productivity will score differently depending on the size and type of fishway required at the site. A site that requires a small low cost fishway will be more cost effective to rehabilitate than a site that requires a large expensive fishway. Therefore sites with simple fish passage requirements will score higher than sites that require large complex fish passage devices (Figure 26). The teams will determine what fish passage options are available for each site during the field assessment of the site. It is therefore essential that both biologists and engineers are present to determine the potential fish passage options.

Figure 26. Rock ramp fishways (left) are cheaper and easier to build than large fish locks (right) and will score higher for this attribute.

Table 11. Scores to be attributed to the estimated cost of providing fish passage at the barrier.

Estimated Cost	Score
a. Low cost small/low nature-like fishway (<0.8m) or short culvert baffles (<0.8m)	5
b. Low-moderate cost small/high nature-like fishway (0.8-1.5m) or low height technical fishway (<0.8m) or tall culvert baffles (>0.8m)	4
c. Moderate cost high nature-like fishway (1.5-2.0m) or medium/low height technical fishway (0.8-1.5m)	3
d. Moderate-high cost large/low height technical fishway (>1.5m)	2
e. High cost large/high height technical fishway (>1.5m)	1

Attribute 12 – Technical Viability of Construction

The logistics for construction of a fishway at the barrier site have are a major influence on the viability of the project. If fishways are located on sites that are far from services and in rugged terrain, their construction can be difficult to manage. In addition sites that require complex fish passage designs are harder to manage through the design and construction process. Sites that have easy construction access and require fishway designs with minimal engineering are much easier to implement and end up being lower in cost (Figure 27). The field team will assess the technical viability of constructing fish passage at a site while conducting the field assessment. They look for access pathways to the site for the movement of heavy machinery, as well as assessing the engineering requirements of the barrier and how difficult the installation of fish passage will be. This can vary depending on the age and structural stability of the barrier, as well as the foundation and bank materials encountered at the site. As the prioritisation process is always trying to achieve the best cost benefit ratios for the rehabilitation, lower cost sites that are easy to access and require limited engineering input score a higher score.

Figure 27. Complex barriers in poor condition (left) are significantly harder to rehabilitate than simple barriers in good condition (right).

Table 12. Scores to be attributed to the technical viability of providing fish passage at the barrier.

Technical Viability	Score
a. Simple installation of current design, with easy access and limited engineering required	5
b. Simple installation of current design, with difficult access or thorough engineering required	4
c. Modest installation of current design, with easy access and limited engineering required	3
d. Modest installation of current design, with difficult access or thorough engineering required	2
e. Complex installation and engineering or a new concept design	1

Attribute 13 – Effectiveness of Providing Fish Passage at the Site.

The effectiveness of fish passage at a barrier is influenced by a number of factors. When retrofitting fish passage to existing structures, the fishway that can be will always have some level of compromised operation due to the limitations of the existing barrier. Depending on what the barrier is and how it is required to operate, the installation and operation of a fishway may be difficult, or very simple. The installation of fish passage on a small overflow weir would be considered simple compared to installing fish passage at an irrigation structure that consists of many gates and is required to pass water to farmers (Figure 28). The degree to which a potential fishway passes all fish on all flows will be determined by the type of structure, type of fishway and flows expected within the system. Structures that can have simple fishway designs which operate over a wide range of flows will score higher as they have a better ability to pass fish. The team will be required to determine the current and future operation of the barrier, how this will be affected by the installation of fish passage and whether the fishway can operate effectively under those conditions.

Figure 28. A full width rock ramp fishway (left) will provide fish passage over all flows, while a partial width fishway (right) can only operate on a low range of flows, dependant on the irrigation requirements of the barrier.

Table 13. Scores to be attributed to the effectiveness of providing fish passage at the barrier.

Effectiveness	Score
a. All species at all migration flows will be able to pass	5
b. All species a most migration flows or many species at all migration flows will be able to pass	4
c. All species at some migration flows or some species at all migration flows will be able to pass	3
d. Some species at some migration flows or few species at all migration flows will be able to pass	2
e. Some species on a narrow range of flows will pass	1

Attribute 14 – Productivity Benefits of Constructing a Fishway

The benefit to the local community that can be derived from the improvements to fisheries productivity is very important within the LMB as many families rely on fish supplies for the protein and calcium in their diets (ICUN 2011). Ensuring that High priority sites should boost fisheries productivity for the local community. The field team will determine at the time of the field assessment how many villages are likely to benefit if rehabilitation of a barrier is undertaken. Sites that are close to villages likely to benefit from fish passage repair, score a higher score than sites further away from villages.

Table 14. Scores to be attributed to the fisheries productivity benefit of providing fish passage at the barrier.

Productivity Benefits	Score
a. Benefit to a number of villages within 3km	5
b. Benefit to a single village within 3km	4
c. Benefit to villages within 5km	3
d. Benefit to villages within 10km	2
e. No villages nearby to gain from improved production	1

Once scoring for all socio-economic attributes has been collated, the scores for each barrier are totalled and added to the score for that barrier from the remote assessment and the biological assessment. The barrier with the highest combined score becomes the highest ranking barrier for repair in this prioritisation process. This final rank will determine the barriers most likely to be rehabilitated. These high priority barriers will provide the largest productive benefit for local communities if they are rehabilitated. The end result of this prioritisation is a report listing the top barriers to fish migration in the target catchment in order of highest priority (see case study for an example).

Step 6 – Select Sites for Rehabilitation

With many thousands of barriers found in the LMB, finding the right barrier on which to undertake rehabilitation is very difficult. To date the selection of sites has not been based on objective scientific criteria but rather by what opportunities were known to local project officers. This has led to the potential situation where repair works will be conducted in a location that is not providing the best fisheries productivity outcomes. The support for works at a site needs to be one of many factors in deciding if works should proceed at the site, not the only factor. As such site-selection methods such as those outlined in the previous chapters have been developed to improve the selection process and enable effective repair to be undertaken. By using tools such as GIS to identify potential restoration sites and by developing assessment criteria that take into account ecological, socioeconomic, ownership and maintenance factors, potential restoration sites can be narrowed to those most likely to succeed. This process can also be undertaken in a relatively short period of time.

The prioritisation process provides a rapid assessment of the barriers in a target catchment, deliberately creating a list that can be rapidly acted upon. Much more detailed prioritisation processes could be undertaken, but these will only use vital resources that could be used for rehabilitation and produce a list quite similar to that produced by the rapid assessment. While the prioritisation process develops a ranked list of barriers to be remediated, it is by no means a definitive list that should necessarily be tackled in the order in which it is presented. It is perfectly OK to tackle barriers future down the list of structures if there are legitimate reasons to do so. Initially it may be preferable to undertake rehabilitation in areas that can be used as demonstration sites for the broader community so as to generate interest and momentum behind rehabilitation projects. As such barriers that are still significant, but not necessarily of the highest priority may be suitable for fish passage rehabilitation. Other opportunities should also be taken if they arise, if a barrier is being refurbished it may be appropriate to undertake construction of fish passage at the same time as other construction is undertaken, even if the barrier is not the highest priority. Funding may also influence the order in which barriers are rehabilitated, as the highest priority structure may be beyond the scope of the funding available for rehabilitation. As such a lower priority, but economically achievable barrier may be undertaken first, this is a much better option than not undertaking any rehabilitation.

If a site has been determined to have funding for rehabilitation and is suitably located for construction, has the support of local officials and community and is of a significant level of priority, then the design and construction should be undertaken. The design and construction process is crucial to the success of a fish passage project, as only small margins for error exist in any design. Any mistakes in the implementation of a design can lead to a fishway being a barrier and not achieving the objectives of the rehabilitation project.

Step 7 – Implement a Design Process

Once a high priority site has been selected from those outlined in the prioritisation process, the next step for that site is to assemble a team of experts. They will undertake a design process that leads to the implementation of successful fish passage either through the modifications of the operation of the structure or the implementation of a fishway. At each barrier there will be a varying degree of site-specific design work required. This will ensure that the fishway functions in conjunction with the existing structure and flow regime, while delivering optimum fish passage outcomes. Fish passage design work is best undertaken using a multi-disciplinary design process that has been successfully implemented, at a variety of scales, for fishway projects in Australia, Europe and the USA.

The design of fishways is a specialist skill and requires the input of both biologists and engineers throughout the project (Clay 1995). While fishways are a capital infrastructure item, their success depends on the incorporation of a site by site understanding of fish movement pathways and likely behaviours. Fish respond to a wide range of factors, such as flow cues, light levels, depth and cover, with each site having its own unique set of conditions. Translation of these biological criteria into engineering outcomes requires close collaboration between design engineers and fish passage biologists, together with the input from the owner of the structure, who will be responsible for its ongoing operation and maintenance. Operator input is essential to ensure that the final design is practical from an operation and maintenance perspective. If the fishway is non-operational then the object of the exercise is lost.

Design Team

Fishway design is a consultative process. Maximum use should be made of existing expertise and local knowledge as this adds to the quality of the outcome. The design team should include or consult with stakeholders who have the following expertise:

Biological

- A fishway biologist with experience in fish passage projects and a knowledge of local fish biology and movement behaviour;

- Where biological knowledge or fish passage expertise is hard to come by, a peer review step may be considered ie. review of the fishway design by an independent (possibly overseas) fishway biologist with experience in providing fish passage at similar structures and preferably with comparable biota;

Engineering

- Design engineer, preferably with fishway and fish passage design experience, but at least with extensive civil, irrigation or road construction experience.

- Construction manager, preferably with experience in constructing and commissioning fishways, but at least with extensive civil, irrigation or road construction experience;

Operational

- The local irrigation officials must be involved at every step of the fish passage design process from the beginning to ensure they are able to operate the fishway into the future.

- Local road operators should also be included in the design process if the fish passage structure also includes a road. This prevents any issues arising from design modifications for fish passage at road crossings.

Proponent

- The presence of the asset owner or funding agency at all elements of the fish passage design process ensures that decisions can be made more readily (e.g. in terms of expenditure), thus avoiding delays.

Design phases

The following phases are set out as a guide to lead the design team through the design process. For minor and simple fishways, the design process can be simplified and steps can be run concurrently (e.g. combine the first design team meeting and site inspection). Also the requirements for data may be abridged and it may be possible to use local knowledge of conditions rather than empirical data. However if the design is for a larger weir or dam, each phase and step should be undertaken and more detailed data collected, to ensure the design is rigorous and successful.

Phase 1 - Collate as much as existing site data as possible:

Without site data it is impossible to deliver a purpose built fishway design that successfully passes fish. Data needed for consideration by the design team includes:

- Fish assemblages at the site(s), up and downstream of the site(s) and any relevant movement and other behavioural data for those species;

- Existing and or modelled hydrological data (eg flow duration curves, Annual Exceedance Probabilities, daily flow data across a range of rainfall years, flow event curves, local knowledge of flow peaks);

- Known or projected headwater/tailwater levels and rate of rise/fall at a range of flows as witnessed by locals or recorded by irrigation officials;

- Details of the downstream tailwater control, its level, the material it is made from and how stable the control is over an extended period of time. This detail is critical as a tailwater control that changes over time can leave a fishway stranded and non-functioning;

- Water storage levels throughout the irrigation and wet seasons;

- Relevant operating rules for the site(s) e.g. frequency, timing, duration and volume of releases from the structure;

- Location and access for operators to maintain operation of the fishway at all times;
- Proposed construction methodologies that are used by local contractors and whether these are suitable for the construction at the site;
- Information about the design, sizing and construction materials of the existing barrier;
- Geotechnical information (bed material, bedrock depth etc) of the site, as this will affect the potential design and cost of that design.

This data should be collected through a number of field studies and site surveys. As far as possible this data should be provided for review prior to the first fish passage design meeting. The depth of detail will vary depending on the complexity and size of the barrier that is being rehabilitated.

Phase 2 - First meeting (once data is collated)

Once all the data has been collated, the design team should meet to discuss the data and the potential designs that could be undertaken at the site. This meeting should include discussions on:

- Existing data, identify data gaps and initiate steps to fill data gaps where practical if required;
- Identify a date by which additional data will be collected and disseminated (before site inspection);
- Discuss operational changes or possible fishway design types (fishways, barrier removal etc.)
- Agree on how the preferred fish passage designs will be arrived at
- Agree on date for site inspections.

Phase 3 - Site inspection

The inspection of the site by the design team is essential for the team to get an understanding of the complexities of the site and how fish passage could be incorporated into the site. The site inspection also allows the design team to interview local operators and community onsite to gain further insight into the operation of the structure that may not emerge during the data collection phase. The site inspection should:

- Inspect the site of the barrier in conjunction with local officials and operators;
- Inspect the stream below the barrier to identify tailwater control points;
- Determine how access to the fishway will be provided for construction, monitoring, operating and maintenance purposes;

- Identify how the hydrological data relates to the barrier and the abutments of the structure;

- Agree on a date for a fishway design workshop.

Phase 4 - Design workshop

The fishway/fish passage design workshop allows fish passage design issues to be identified and discussed with input from all the relevant stakeholders and experts.

It is critical that the proceedings and outcomes of the workshop are captured and accurately recorded by a person with sufficient technical understanding. These minutes will be an important record should back reference need to be made (eg. relating to design intent, operational constraints, design assumptions etc). Fish passage issues to be discussed include:

- Fishway types to be considered for providing upstream passage at the barrier;

- Flow conditions below the barrier over the range of fishway operation;

- Entrance and exit points of the fishway;

- How the fishway is to be incorporated into the existing barrier;

- Operation and maintenance requirements for the fishway and their design implications.

A fishway options assessment spreadsheet may then be completed (Figure 29). This is a process for scoring various types of fishways that could be suitable for the site, against performance and other design criteria. The spreadsheet allows weightings for different criteria and has proved to be a useful tool for choosing an appropriate design.

Fishway design criteria

The design workshop and criteria matrix allow the development of fishway design criteria for the site. The agreed design criteria will underpin the development of a concept design and subsequent detailed design. The criteria in this section are a selection of the most common design criteria, however, other criteria may be considered due to the unique operating environment or location of the structure, and should be included where appropriate. Useful design criteria include:

General

- The quality of materials and components used in the construction of the fishway should be commensurate with its intended service life and to the same standard as the barrier infrastructure;

- Fishways should be properly integrated into the existing infrastructure so that they are operated and maintained as part of the overall structure;

- The fishway should aim to cater for the whole fish community in terms of size classes, life stages, swimming abilities and biomass;

All scores rated from 1 (Poor) to 5 (Very Good)		Vertical Slot Fishway		Bypass Fishway	Rock Ramp Fishway	
		1A	1B	2	3A	3B
CRITERIA		Right Bank	Left Bank		Lateral Ridge	Random Rock
	Weighting	Score	Score	Score	Score	Score
FUNCTIONALITY						
Effective in passing target species						
Small fish at low flows	4	4	4	5	4.5	4.5
Moderate size fish at moderate flows	4	3.5	3.5	4	5	5
Suitable for HW Range	4	5	5	3	4.5	4.5
Suitable for TW Range	3	4	4	4.5	5	5
Ability to adapt for change in TW	3	2	2	4	5	5
Entrance conditions (attraction)	4	3	3	4	5	5
Downstream passage	4	3	3	4	5	5
Ability to monitor performance	1	4	4	3	2	2
Sub-total for Functionality		96	96	108.5	128	128
OPERATION						
Ease of Maintenance	3	3	3	3	4	2
Sediment accumulation	4	3	3	2	5	5
Debris accumulation	4	4	4	4	3	4
Sub-total for Operation		37	37	33	44	42
ENVIRONMENT						
Footprint	3	5	5	1	3	3
Aesthetics	3	3	2	5	4	4
Sub-total for Environment		24	21	18	21	21
RISK						
Public access / Safety	5	5	4	3	4	4
Vandalism	3	4	4	2	5	5
Constructability (constraints on construction)	3	3	5	2.5	4	4
Sub-total for Risk		46	47	28.5	47	47
Total Overall Score		203	201	188	240	238

Figure 29. An example of a fishway design criteria matrix, providing a guide to suitability of each of the proposed fishway designs to the barrier.

- Fishways should have the capacity to provide both upstream and downstream passage all year round for the whole fish community;

- The fishway should be designed to be operational all year round when there is a flow or a release at the site;

- The operational range of the fishway should be maximised;

- The fishway design should allow for changes in tailwater levels (eg be constructed to operate down to 0.5 metres below minimum tailwater);

- All releases from an impoundment should be directed first through the fishway as a priority;

- The fishway design should aim to minimise the time that it is non-operational due to maintenance issues, such as siltation, debris, breakdowns;

- Adjacent outlet works should be screened or otherwise designed and placed to prevent fish passing through or becoming trapped in these works;

- Outlet works need to be positioned so as not to interfere with fish access to the fishway entrance;

- Spillway overtopping flows should initiate and terminate adjacent to the fishway or be directed parallel to the fishway entrance;

- There must be a continuous attraction flow at all times at the fishway entrance when operating;

- Attraction flow velocities must be sufficient and variable to attract the whole fish community;

- Water supply for the fishways and attraction flows must be sourced from surface quality (or equivalent) water;

- Trash is excluded from the upstream fishway exit and downstream fishway entrance with designs that ensure that fish can access the exits and entrances and that the fishways are not blocked or damaged by trash.

- Appropriate light levels must be maintained at fishway entrances.

Entrance

- Fishway entrances must be sited where fish can access them over the full operational range of the fishway (Figure 30);

- Fish attracted to a spillway must be able to access the fishway without having to swim back downstream;

- Turbulence and velocities at the fishway entrance need to be balanced to ensure there is sufficient attraction flow for fish without precluding smaller fish;
- Entrance slot widths are suitable for the whole range of fish to be encountered at the site, or made adjustable and assessed through the monitoring program;
- Adequate holding chamber dimensions are provided for the fish biomass at the site (for lock, lift, trap and transfer type fishways);
- Adequate hydraulic flow conditions suitable for all fish should be maintained within the fishway;
- Attraction flow diffusers must be fixed on the back wall of the holding chamber (for lock, lift, trap and transfer type fishways) and positioned so as not to create excessive turbulence and recirculation;

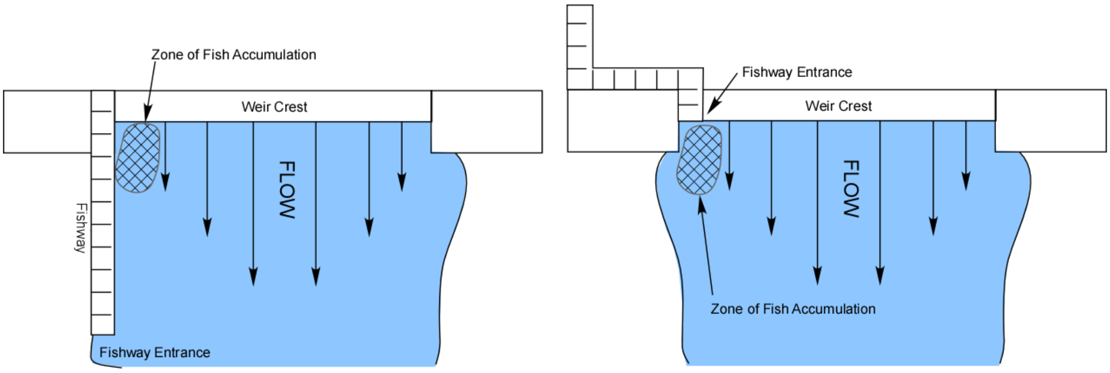


Figure 30. Poor fishway entrances (left) are far away from where fish accumulate below a weir, while good entrances (right) are easily found by fish the at the weir.

Exit

- Fish should exit so as to avoid entrainment onto outlet work screens or avoid being washed back over the spillway during overtopping (Figure 31);
- Cover should be provided for fish moving from the exit upstream if the exit is into deep water away from the bank;
- Fish should exit at surface water level;
- Weeds should be controlled at the fishway exits to ensure that fish swim into water free of weed mats and that the fishway is not clogged with weeds.

Outlet works (if present)

- Outlet works should be adjacent to the fishway
- The orientation of the outlet works water jet is angled so that it does not mask or isolate the entrance to the fishway or impinge on fish moving up the adjacent riverbank
- High flow releases should not cause confusing flows at the fishway entrance.

- Intake screens dimensions must be such that small fish are not drawn through the outlet works and velocities should be low enough that fish are not impinged/entrained on the screens.

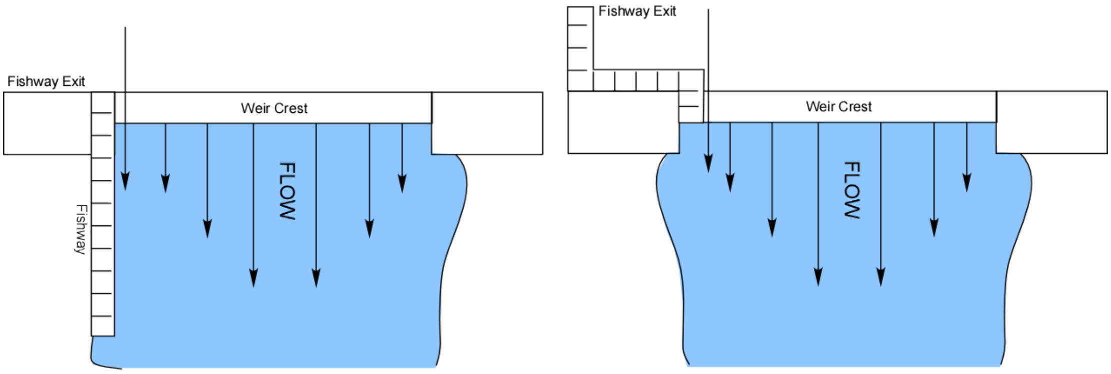


Figure 31. Poor fishway exits (left) are close to where fish can be swept downstream, while good entrances (right) are located close to the bank in slow flowing water.

Phase 5 - Concept design

Once the design team has considered all of the relevant design criteria for a site and conducted an options analysis of the various designs available, it can then move onto creating concept designs suitable for presentation to proponents and operators. The concept design may display a number of options for the implementation of the chosen design at the site and take into consideration issues identified by the design team. The concept designs is then presented to all relevant stakeholders and the options explained. Through this process, proponents and operators can visualise how the fishway design will be implemented on the barrier, giving them the opportunity to raise any issues that they identify. A review process by an external party who has no stake in the project should also be undertaken to give an independent assessment of the viability of the fishway design. Once this process has been completed and all stakeholders have agreed on what option to take forward to detailed design, the final fishway design can be drafted.

Phase 6 – Detailed Design

The detailed fishway design will incorporate all the information collated throughout the previous five stages of the design process and distil these down to a set of detailed design drawings (Figure 32), construction instructions and various post-construction plans. It is critical that the detailed design drawings are reviewed by the whole design team whenever there are changes made to ensure that the final product has not been compromised for fish passage. It is very common when developing final designs for engineers to make changes to the design for legitimate engineering reasons, only to have those changes compromise fishway operation to such an extent that the fishway does not function. To prevent this ongoing review by the whole team is essential.

In addition to the detailed drawing the detailed design should also include specific instructions on how the fishway should be built. The misinterpretation of a design by construction crews can lead to the complete failure of the design and as such

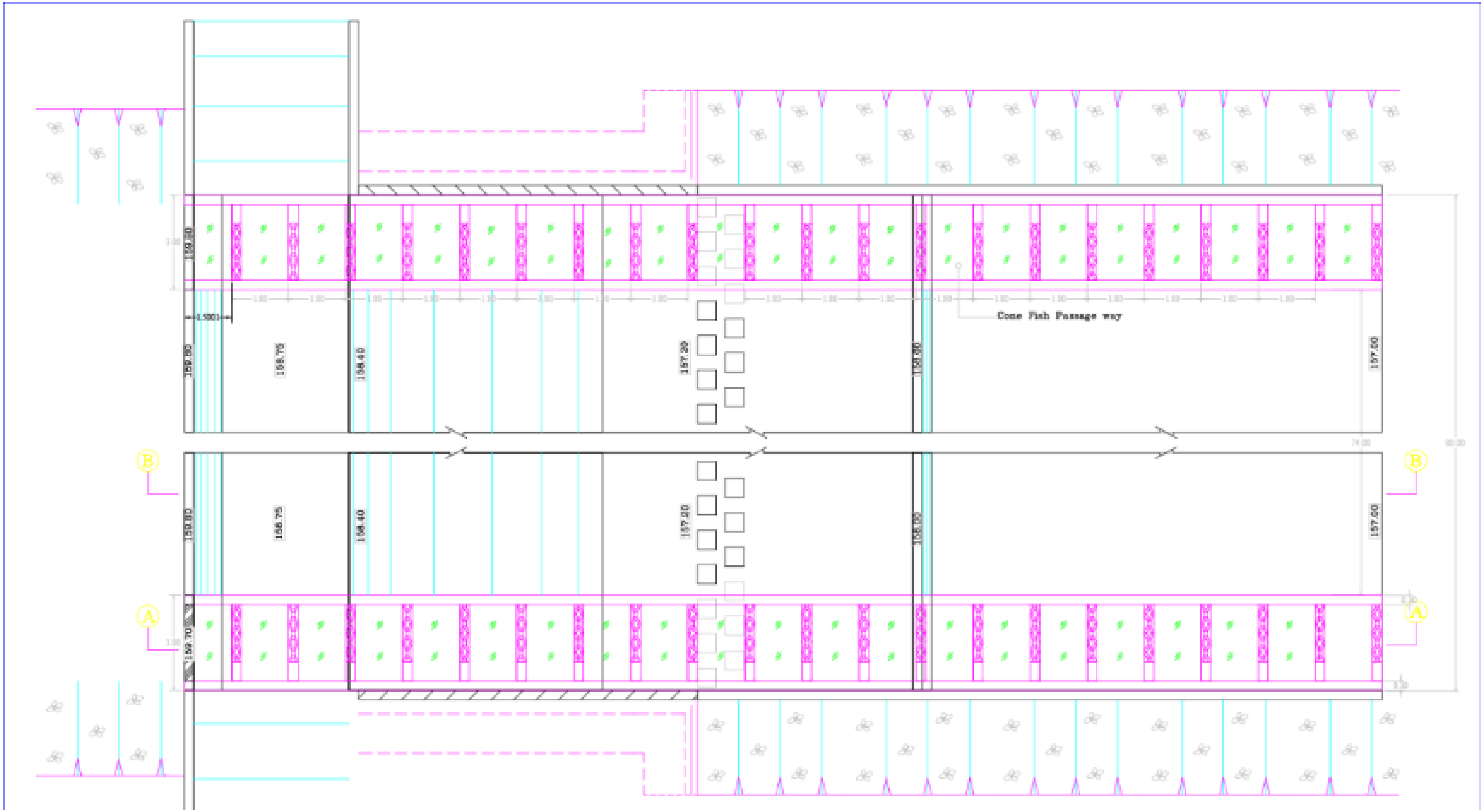


Figure 32. Detailed design of a cone fishway in the Xe Champhone catchment.

instructions should be comprehensive enough that construction crews are able to implement the design easily. To this end, a communications plan between the construction contractors and the design team should be drawn up to ensure the team's involvement and accessibility to the site during construction. The inclusion of a fishway inspection program for the design team during and close to completion of construction is essential to ensure that any errors in the design can be addressed prior to the de-mobilisation of construction crews.

The detailed design should also develop a number of plans that will assist with the commissioning, operation, maintenance and monitoring of the fishway after the completion of construction. These include:

Commissioning Plan

- Development of a post-construction Fish Passage Commissioning Program that sets out how the fishway will be tested in order to fine tune the operation;
- This will determine if there are any structural issues with the constructed design;
- It will identify how the issues raised can be improved to make operation more efficient.
- The plan should identify when the commissioning will be done and by whom and give a clear line of responsibility for rectifying defects:

Operation and Maintenance Plan

- By developing the Fish Passage Operation and Maintenance (O&M) Plan up front, there can be clear linkages between the design intent and the implementation of that design. As with any piece of infrastructure, a fishway will need long-term management and maintenance. Documented and agreed-to plans should be set up at this point and serve as a reference linking the design intent for the fishway with the operational outcomes.

Monitoring Plan

- Monitoring will assess fish passage at the fishway (as opposed to the commissioning which assesses the hydraulics of the fishway) and compare the results with the design intent. Development of a Fish Passage Monitoring Program is addressed in step 10 of this guideline.

Community Engagement Plan

- Community education programs relating to the completed fishway should be developed to increase community acceptance of the technologies and to improve community ownership of the structures. This will lead to the community looking after the fishway and not using it as a device to harvest fish.

The final fishway design containing this information is then assembled together with any records of meetings, concept and final designs, commissioning, monitoring and operation and maintenance plans as a record of the design process.

Design Options

There may be several fishway design options for a given site and the design process will determine which is the most suitable. Often a combination of designs will be the most suitable option. Recent research in the Lao PDR, the first on the use of fishways by LMB fish, has established a number of designs that are suitable for local fish (Baumgartner et. al. 2012). Designs that can be used to rehabilitate fish passage at new and existing structures include:

Rock Ramp Fishway

Rock ramp fishways are commonly used for low barriers up to about two metres high. They are essentially a series of rock ridges placed immediately below a barrier, creating a low slope pool and step that simulates a rocky stream bed (Figure 33). Larger boulders are placed in ridges across the rock ramp, creating pools of low flow and low turbulence. Each of the ridge rocks has a gap between it and the ridge rock beside it, through which the water flows, allowing fish to move from pool to pool and over the weir.

Figure 33. Rock Ramp fishway on the Goulburn River, Victoria, Australia.

Cone Fishway

Cone fishways are designed on a similar principle to the rock ramp fishway, but uses concrete to create the ridges. This design is particularly suitable for sites where the supply of rock is limited. The concrete cones create a series of ridges that provide small steps and pools of low turbulence and velocities through which fish can ascend (Figure 34). This design has recently been installed on the Pak Peung regulator near Paksan in Boxhimalay Province, Lao P.D.R. and has been successfully assessed in the 2014 wet season. Monitoring indicates that the design is successfully passing fish (Baumgartner et. al. 2014.

Figure 34. Concrete cone fishway constructed at Pak Peung Regulator, Lao P.D.R.

Culvert Baffle Fishway

Culvert baffle fishways consist of a set of vertical protrusions from the walls of a culvert that break up the water flow, slow the water down adjacent to the culvert walls and provide resting areas and migration pathways for fish (Figure 35). The baffles are usually made of steel and fixed to the wall with suitable materials. They work on the same principal as other fishways, in that they break up the fast flow in to a series of small steps with manageable velocities for fish. They are most suitable for application at floodgates where culverts are often used in association with the gates.

Figure 35. Culvert baffle fishway constructed on Marion Creek, Queensland, Australia.

Vertical Slot Fishway

This design consists of a concrete channel extending from the top of the weir (headwater) to the base of the weir (tailwater). Within the channel, baffles are inserted at regular intervals along the length of the channel to slow the velocity of the water. Within each baffle there is a vertical slot through which water is transferred to the next pool downstream (Figure 36). This creates a series of pools and small steps, with low velocities that fish are able to swim through easily. This is one of the most successfully applied designs worldwide, but can have high capital costs.

Figure 36. Vertical slot fishways constructed on Sheepstation Creek (left) and Gooseponds Creek (right), Queensland, Australia.

Fish Locks

A fish lock provides passage upstream through a series of hydraulically operated gates that regulate the water levels within the lock. The fish enter the lower section of the lock, while the water level in the lock is equal to the downstream water level. After a set period of time the fish lock is closed and the water level is raised to be equal to the headwater storage level. Once this happens an upper gate is opened and the fish are then able to enter the storage area. Fish locks have been installed and operated on sub-tropical and tropical rivers in Australia for over twenty years (Figure 37). When operational, the fish locks are very successful at passing fish upstream and downstream.

Figure 37. Dumbleton Weir Fish Lock on the Pioneer River in Central Queensland, Australia.

Fish Lift

Fish lifts are a mechanical means of passing fish upstream and have been successfully used to pass fish over several high dams in Australia and particularly in the USA. The fish lift utilises a hopper system that lifts large bucketful's of water and fish up and over the dam. Fish are attracted into the bottom of the structure in a similar manner to lock fishways. After a set period the hopper is lifted, either on rails or on a crane, up and over the dam and lowered into the storage upstream, where fish are released Figure 38). When operational the fish lifts are very successful at passing fish upstream and downstream.

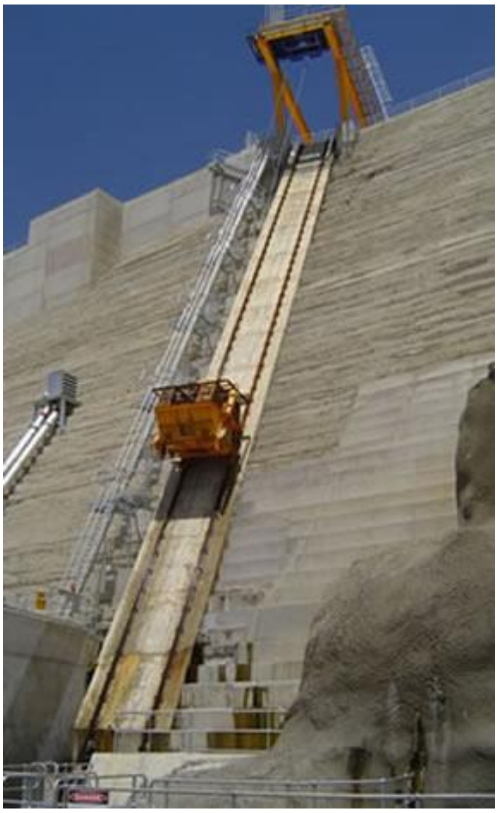


Figure 38. Paradise Dam Fish Lift on the Burnett River in South East Queensland, Australia.

While not all of the information outlined in this step of the process will be required for all structures, it is worthwhile following the general principles. Smaller structures may be able to skip some of the phases of the design process as they are likely to be simpler to construct. However it should be noted that there is no one fishway design that fits all structures, the design of fishways is a specialist skill and requires the input of both biologists and engineers throughout the project.

To ensure that effective fish passage is achieved requires a rigorous design process that considers all factors associated with the project. Using the outlined design team, design process and design options will ensure that a suitable fishway can be incorporated in the structure under review. A design team with a broad experience in both engineering and biology is the basis of every successful fish passage rehabilitation.

Step 8 – Undertake Construction

Once a design has been finalised, construction should be planned along the following principles:

- All fishways should be constructed according to the final design drawings agreed by the design team. Any changes to the final design must be referred back to the team so that biological, engineering and operational considerations can be made. Experience has shown that very minor amendments to fishway designs during construction have the potential to significantly reduce their effectiveness.

- The design team fishway biologist should attend at least one pre-completion site inspection, to allow identifiable deviations or issues to be documented and rectified while construction workers and machinery are still on the site. At rock ramp fishways, the presence of a fishway biologist at the beginning as well as close-to-the-completion of construction is required to ensure the correct placement of rocks is understood by the machine operators.

- The design team biologist and engineer should also attend a close to completion (or at completion) inspection, so that the general form of the fishway can be checked for visible errors. Again, this should take place while construction workers and machinery are still on the site to allow identifiable issues to be rectified immediately.

- Commissioning of the fishway is a key step that also requires the presence of the design team biologist and engineer. Commissioning should proceed according to the Commissioning Plan and occur as soon as possible after completion of the fishway, to optimise the chances of defects being rectified by the construction team. However, commissioning can be delayed until flow conditions are adequate at the site to properly test the structure.

- For more major fishways, monitoring access and equipment, such as traps, lifting equipment etc will need to be installed and tested as part of the construction/commissioning phase.

- The quality of the materials and components used in the construction of the fishway should be serviceable and commensurate with its intended service life and operation. Generally this would match or exceed the life of the barrier.

- Where possible employ construction managers and teams that have experience in installing major fishways and fish friendly stream crossings previously.

- Restrict construction works to months of least fish movement and lower flows in order to minimise impacts on fish as well as water quality. The months of least fish movement will vary depending on location, altitude and hydrology and should be investigated for each site.

- Waterway bed and banks should be returned to their original profile and stability, so that long-term fish movement at the site is not compromised.

- It is important to note that minor structural adjustments are likely to be required to fishways in almost every case. Generally, these adjustments are not fully identified until after the fishway has been completed, and commissioned and operated for a sufficient period to allow a full performance monitoring program of the fishway to be undertaken. This may go beyond the handover period from construction to operation. Some allowance will need to be made to pay for and undertake the required adjustments, particularly where there are higher risk design elements or assumptions.

The design and construction of fishways is an ever developing field, with new knowledge from previous fishways inputting into the design and construction of new developments. The successful development of criteria for fish passage at a site may be able to help sites in the vicinity with similar fish communities implement their design better. Projects such as the "*Optimising fish-friendly criteria for incorporation into the design of mini-hydro schemes in the Lower Mekong Basin*" (Thorncraft et. al. 2013, Appendix 2) and "*Improving Fish Passage in the Mekong and Murray Darling Basins*" (ACIAR 2009, Appendix 3) have attempted compile some of the results of monitoring of experimental fishways into a set of criteria for fish passage. However while these criteria are very valuable, they only apply to the fish communities in the area of study. They may be used as the basis for design criteria for other areas, but local information should be incorporated into them to ensure that there is the highest possibility of successful fish passage outcomes. The incorporation of local data and site information cannot be overstated in determining the success of a fishway project.

Step 9 – Operate and Maintain Fishway

Post-construction and post-commissioning is really the critical phase for a fishway's success, yet often the least resourced. Some fishway types (such as rock ramps) can be very low maintenance, but all fishways will need some degree of regular inspection, maintenance and repair to retain their functionality. The maintenance program must be implemented for the life of the structure. Operation, maintenance and repair are key design considerations, particularly in remote areas and this is why operators are such an integral part of the design team. The O&M plan developed during the design phase allows the operator to plan and resource O&M requirements well in advance.

A fishway O&M plan might include:

- General operating rules for the fishway;
- A maintenance program to maintain both fish passage and the fishway structure;
- Contingency plans in case of structural or mechanical failure of the fishway or associated infrastructure;
- A process that ensures timely repair of damaged or defective fishways;
- Reporting procedures about the operational status of the fishway;

This is also the phase where some level of monitoring of fish passing through the fishway can be implemented, with a view to optimising the fishways operation. The optimal operating regime for the fishways will be an outcome of the results of monitoring as well as a degree of trial and error. It is not expected that the fishway will be optimally operated from day one. However, there are some minimum operating requirements that the designers will have considered;

- The fishway should be operated as set out in the design specifications, unless/until monitoring results suggest otherwise;
- Where practical fishways must be operated in a manner that resembles the inflow and outflow conditions at the barrier, relating to releases and natural flows within the system. Research has shown that cues for fish movement incorporate climatic cues, water quality cues as well as flow volumes. Sensitivity to these factors in the operation of the fishway can have dramatic beneficial impacts on fish numbers;
- Other seasonal fish migration requirements must be identified and included in the operating requirements for fishways, irrespective of flow;
- Any releases from a weir or dam should be directed down the fishway as a priority up to the capacity of the fishway and the fishway should be operated during all releases;

Step 10 – Evaluate the effectiveness of the Fish Passage Rehabilitation

All fishways constructed should have some level of monitoring, to ensure that they are operating according to their design specifications and, where relevant, to work out the optimal operating regime for the fishway. Monitoring programs should be developed in consultation with the design team biologist, to ensure that design assumptions can be tested and ratified. The monitoring program will vary with the size and complexity of the fishway constructed, with those on larger structures or larger catchments requiring more detailed monitoring. Small structures that carry a reduced risk of inadequate operation may only require a limited monitoring program to determine if they are operating to design.

To evaluate the effectiveness of any fishway, the monitoring needs to establish the successful passage of fish entering, traversing and exiting the fishway. It also needs to determine that the fishway is providing passage for the whole fish community (species and size classes) under the design conditions. In addition it is also useful to understand the impact that the inclusion of fish passage has on the whole fish community in the broader catchment. To achieve these outcomes, there are three broad categories of monitoring for a new fishway, direct monitoring of the new fishway, broader catchment scale monitoring of the fish communities and direct monitoring of the fish through tracking technologies.

Which technique is used in any monitoring program will be determined by the complexity and size of the project, the budget associated with the project and the questions that need to be addressed in the program. Generally small, low risk projects will have less detailed monitoring requirements than larger, higher risk projects. Project that occur in new areas where there is limited fisheries knowledge will also require greater monitoring requirements as the collection of knowledge for future projects should be a priority for all projects. Only through the comprehensive collection of rigorous data relating to how, when and why fish are migrating can future fish passage projects be improved. This is especially important in the Lower Mekong Basin where there is limited knowledge of the requirements for fish passage.

Fishway Monitoring

The direct monitoring of the fishway will establish if the fishway is operating as per the intent of the design and construction process. This monitoring also provides the opportunity to refine the design and operation of the fishway, by direct observation of the fish community using the fishway during flows.

Sampling is conducted to compare catches at the entrance and exit of the fishway. Where there is variation in results between the entrance and exit, this may indicate that the fishway is operating sub-optimally and will determine if any species or size classes are unable to ascend the fishway. The sampling should be undertaken with suitable traps designed to capture all fish species and size classes in each location (exit and entrance). In fishway designs that are difficult to trap, such as rock ramp fishways, alternative methods such as electrofishing or cast netting at the entrance and exit of the fishway may be used in place of the traps.

Traps should be set as paired replicates of the exit of the fishway versus the entrance of the fishway, the period of time required for the sampling will vary, depending on the size and complexity of the site being studied. The minimum sampling that could be undertaken would consist of 5 days for each sampling occasion, this would be suitable for small structures. A typical 5 day sampling would have one paired replicate run during daylight hours each day and one paired replicate overnight for two consecutive nights (see Figure 39).

The total quantity of replicates undertaken will be proportional to the size and complexity of the fish passage provided. Low-level fishways will only require a single weekly set of sampling during peak times (Figure 39), while larger structures may require many replicates over the entire migration season. The risk of low-level fishways failing to provide adequate fish passage is lower, so the intensity of sampling is also lower.

	Time	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**
	AM	Exit	Entrance	Entrance	Exit	Exit
Location	*PM*	Entrance	Exit	Exit	Entrance	Entrance
	Night	Entrance	Exit	Entrance	Exit	

Figure 39. Trap locations for an example 5 day sampling regime of the entrance and exit of a low level fishway

Sampling should be conducted over a wide range of flows throughout the migration season, especially during months when peak numbers of fish are likely to be migrating. The sampling of a fishway during high flows can be dangerous to team members and should only be undertaken if the sampling locations at the top and bottom of the fishway can be made safe.

Traps used in fishway sampling are of a mesh aperture suitable to capture all species and size classes likely to ascend the fishway. The traps collect fish from the full width of the fishway and are set either directly at the entrance to the fishway or directly above the exit of the fishway. These traps should be constructed using a steel frame covered by fine mesh netting, suitable to trap small bodied fish. Cones at the entrance of the trap should extend the whole height of the trap. The cones taper into the body of the trap and are used to reduce fish escapement back out of the entrance of the trap once the fish have entered the trap (Figure 40). Electrofishing/cast netting, if used, will collect fish from directly below the fishway in place of the bottom trap if it is not feasible to use a trap e.g. due to shallow water depths at the locations. Electrofishing sampling consists of sweeps across the pool below the fishway with the electrofisher unit, while cast netting requires ten casts into the waters across the width of the fishway entrance.

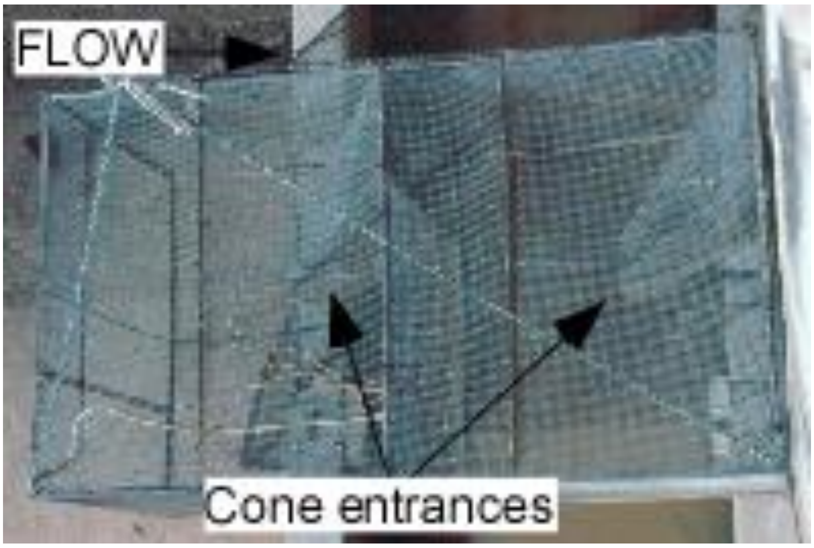


Figure 40. A double cone trap, showing the location of the cone entrances.

All fish collected with traps, electrofishing or cast netting should be identified to species level, measured for length and recorded on data sheets. Water conditions such as quality and flow should also be recorded each day. All fish species, counts and length data, together with water quality data, flow and fishway function observations should then be entered into a computerised database. The biological data collected is analysed to look at any differences between fish caught entering the fishway and those successfully exiting the fishway. Once analysis has been completed a technical report outlining the results of the monitoring and success of the fishway at passing fish and any modifications required to improve the fishway is completed.

Catchment Fish Community Monitoring

The monitoring of the fishway directly will provide information on the ability of the fishway to pass fish upstream. While this information is vital to determine if the fishway works, broader fish community monitoring will be required to determine if the fishway is increasing the fisheries productivity of the system.

To this end a sampling program that attempts to identify the changes in fish communities upstream and downstream of the structure should be undertaken. This sampling program collects data on the fish communities at several sites upstream and downstream of the barrier before and after the construction of the fishway. Sampling in this manner will allow the comparison of fish communities from before and after the commencement of fishway operation. The presence upstream of more fish or fish species not found prior to fishway operation demonstrates that the fishway is positively impacting the fish community.

This fish community data can be collected in a variety of ways, gill, seine or drum nets, electrofishing or fish traps would all be suitable techniques. The sampling may also collect fisheries data from local fisher persons who fish in the vicinity of the fishway. All data however, should be collected in a manner that is easily compared over the life of the sampling program. As such the method for collection of data should be fixed at the commencement of the sampling program.

A minimum direct sampling program could consist of gill net sampling with a range of mesh sizes from 1” to 6”, at 4 locations downstream and 4 locations upstream of the fishway twice per year over a period of three wet seasons (Figure 41 and Figure 42). Gill nets are set for a standard period of time at all locations (e.g. 3 hours per net per site) in a closely spaced (within 10 km) sampling run (i.e. over 4 days). Much like the fishway sampling, depending on the size of the system and complexity of the fishway and fisheries this sampling program may need to be extended to more sites, or a longer period of time. Each site needs to have a monitoring program developed that is suitable for these factors and will vary from the options presented here.

	Time	**Day 1**	**Day 2**	**Day 3**	**Day 4**
Location	*AM*	Site 1	Site 3	Site 5	Site 7
	PM	Site 2	Site 4	Site 6	Site 8

Figure 41. Gill net locations over a typical 4 day sampling run.

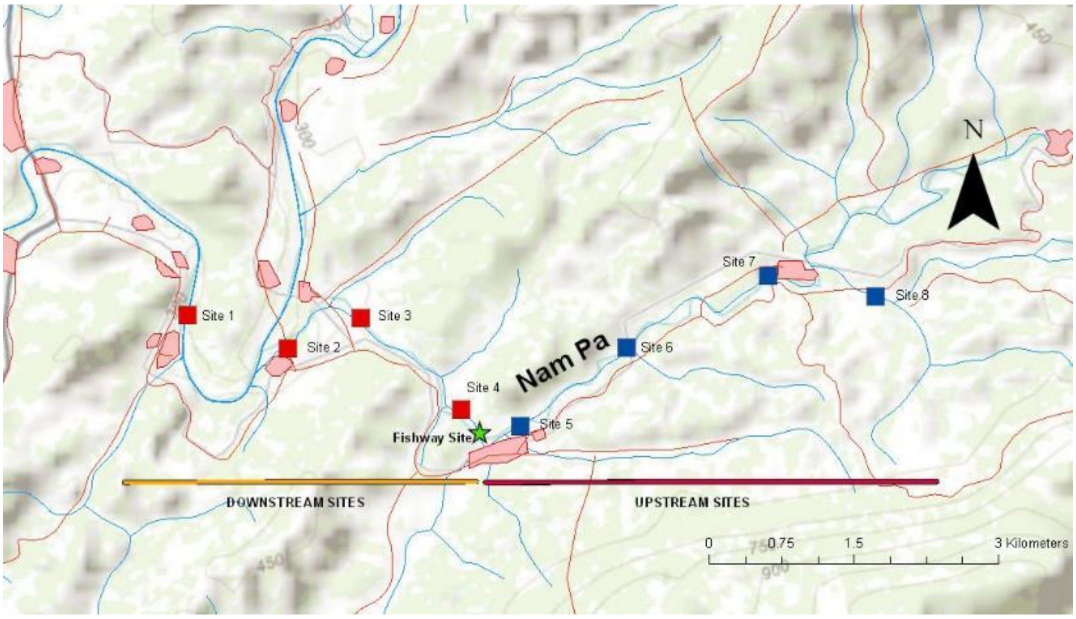


Figure 42. Typical sampling locations associated with the construction of a new fishway. Sites are located upstream and downstream of the fishway location.

All fish collected in the fish community sampling are identified to species level, measured for length and recorded on data sheets. Water conditions such as quality and flow are recorded at each sampling location. All fish species, counts and length data, together with water quality data, flow and fishway function observations should then be entered into a computerised database. The biological data collected is then analysed to look at any differences between fish caught upstream and downstream of the fishway before and after construction. In general sampling should show that there are more fish and species accumulating below the barrier prior to fishway construction and that these accumulations reduce after construction so that fish numbers are more evenly spread across sites (Figure 43). Once analysis has been completed a technical report outlining the results of the monitoring and success of the fishway at passing fish and any identifying modifications required to improve the fishway should be completed.

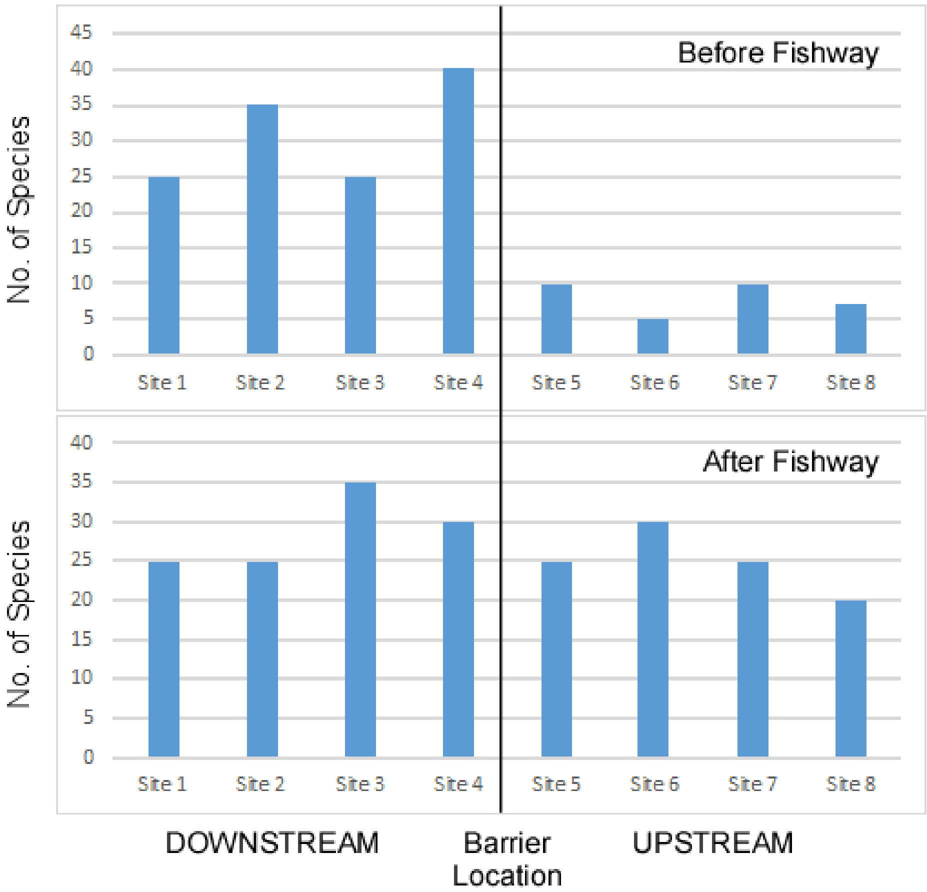


Figure 43. Idealised sampling results from sites downstream (left) and upstream (right) of a fishway before (top) and after (bottom) construction. After the successful construction of the fishway the number of species able to move into the upstream waters increases, improving productivity in the system.

Local Fishing Community Monitoring

An additional method for determining the success of modification of a structure to improve fish passage could include socio-economic surveys of local fishing communities. These would be undertaken both before and after fishway construction, over a minimum of two wet seasons.

The Socio-economic surveys should focus on four key metrics;

1. Determine the baseline degree of fish harvest and consumption upstream and downstream of the structure,

2. Monitor local markets and other fish marketing pathways (fish traders) affected by the structure,

3. Identify the contribution of fish from upstream and downstream of the structure to household incomes,

4. Quantify the arrangement of local fish-based economies.

These surveys should be conducted at three main levels (village, household and individual fishers) using approaches that have been applied in other areas of the Lower Mekong Basin (See Hortle, Troeung et al. 2008). The study should focus on local villages near fish passage barriers identified as part of a prioritisation process. Village sample surveys should involve face-to-face interviews with village chiefs and experienced fishers with a general knowledge of fishing practices in their region. Fish markets within each village and fish traders should be monitored to determine any fluctuations in fish prices both seasonally, and before/after structure modification. A number of villages should be surveyed in the study region to gauge the degree of spatial variation in fishing rates.

Household surveys, within each village, should be undertaken to determine overall consumption and catch of fish at a household level. Surveys should be undertaken several times annually, both before and after structure modification, to determine seasonal changes in catch and consumption rates. This information can be correlated with seasonal fish migrations to determine if there is a link between the two factors. Information should be obtained through a face-to-face survey with the head of house, and a number of houses should be surveyed in each village.

Individual surveys are then required to obtain information on individual fishing practices. This is necessary to determine the range of fishing techniques and target species. Any variation in fishing effort and sampling method must be taken into account when analysing data at the village or household level because effort can greatly bias results. This method will involve surveying both male and female fishing activities. A clear picture of group fishing activities and expedition fishing both into and away from the study area will also be developed. Villages should be presented with the results of the study to provide a basis for improving community-based fisheries management. Metrics describing fisheries production should be refined once structure modification has been completed.

Tracking of Fish Movements

Another technique to determine the success of the installation of a fishway is the direct tracking of fish that are using the system to move upstream. There are a number of technologies that can be used to track the movements of fish, including those that place a tag in the fish to track its movement through various sensors such as PIT tags and Acoustic tags. There are also a number of indirect monitoring techniques that use high technology equipment to monitor the fish’s movements with the river of fishway such as DIDSON sonar devices. These direct tracking techniques are able to directly track small numbers of fish in the population and determine their behaviour and success at passing barriers. The undertaking of a direct tracking project is very expensive and requires the input of experts in this field and should not be undertaken without their input.

Conclusion

The presence of thousands of barriers to fish passage in the Lower Mekong Basin is a huge problem for the continuation of local fisheries. It has been clearly demonstrated that these barriers are negatively impacting fisheries and the rehabilitation of the many barriers in the basin is desperately needed. However the identification of suitable sites for rehabilitation is difficult due to the sheer size of the task required to visit these thousands of barriers. As such a process that can narrow down the considerable number of sites into a more manageable prioritised list is required.

The prioritisation process outlined in this report offers just such a process and is able to filter the large number of barriers into a list of high priority sites. Through the use of remote imagery and available GIS data and using a combination of the score and rank and optimisation prioritisation techniques, this process will provide the most appropriate prioritisation given the resources that are currently available in the basin.

This methodology has already been successfully used in catchments in the Lao P.D.R as well as northern Australia. In the sub-tropical Fitzroy River basin (Queensland, Australia), the prioritisation process proposed successfully identified and prioritised over 12,000 barriers to fish migration and has led to an ongoing rehabilitation program that has constructed over a dozen fishways in the last 5 years. Further north, in the (tropical) Mackay Region (Queensland, Australia), another prioritisation exercise has led to the investment of over $1M in the construction of more than twenty fishways that have opened up more the 500km of stream habitat for local fish communities. In the Mekong basin the prioritisation within the Xe Champhone has successfully identified and prioritised nearly 800 barriers to migration and has led to the commitment to construct a demonstration fishway on the Huay Suoy.

Once the identification of high priority sites has been completed the implementation of a design, construction and monitoring program is potentially challenging. The incorrect placement of what appear to be minor components of the design can have major implications for the provision of successful fish passage. The simple act of changing the drop between cells of a vertical slot fishway from 100mm to 200mm completely alters the success of the fishway, with the larger drop preventing fish passage. The design process as outlined in this document has been developed through past experience to minimise the risk of failure. By following these procedures and using a multi-disciplinary design team, project officers can ensure that a suitable fishway is constructed at the site, that it is operated and maintained correctly and demonstrated to work adequately at improving the fisheries productivity of the system.

Recommendations

An investment strategy should be developed for the prioritisation of catchments throughout the Lower Mekong Basin

This investment strategy should be promoted with suitable NGO's and Government officials to attain funding for fish passage prioritisations in each country

Plans should be drawn up for the investigation of barriers in target catchments in Cambodia (Stung Pursat), Laos (Nam Pa), Thailand (Nam Kam) and Vietnam (Mekong Delta).

Once funding is secured:

a) Appoint suitable international experts to guide the prioritisation process across the LMB

b) Appoint national consultants to implement the prioritisation in target catchments in each of the member countries and produce a field guide for each countries survey teams

c) Commence organising local groups (universities, irrigation/fisheries officials etc) to undertake training for the field appraisals

d) Collect appropriate local data for input into the prioritisation process from local governments, MRC and NGO's

e) Determine appropriate local scoring of each criteria

Prioritisations should then be undertaken in the target catchments to produce investment strategies for fish passage projects in those catchments.

Once prioritisations have been completed and suitable fish passage rehabilitation sites identified, MRC should convene expert panels to oversee the design, construction and monitoring of fishways that are constructed. These panels should contain suitably qualified experts in fish passage, as well as local engineering, irrigation and fisheries officials.

To further assist the development of engineering expertise a further engineers guide to fish passage installation at irrigation structures should be completed. This design would assist irrigation engineers by detailing the implementation of fish passage at irrigation structures

Glossary

AFPS – Australasian Fish Passage Services provides fish passage services throughout Australia and SE Asia.

Arcmap – The main component of Esri's ArcGIS suite of geospatial processing programs, it is used primarily to view, edit, create, and analyse geospatial data.

Barrier – Any structure across a waterway that inhibits the movement of fish up and down the waterway.

Dam – A barrier across a waterway that has a separate spillway structure, they are large structures, usually greater than 5m high.

Dipterocarp forest – A forest largely dominated by tropical hardwood trees that are long-lived and can grow to exceptional sizes.

Fish Friendly – A structure that provides easy access for fish to upstream habitats through the design of the structure of inclusion of a fishway.

Fish Passage – The movement of fish in both upstream and downstream directions past an obstruction in the waterway.

Fishway – An engineered structure that provides fish passage past a barrier.

Floodgate – A structure that prevents floodwaters from entering the floodplain, usually consists of steel flaps that can let water out of the floodplain, but not let water in.

Georeferenced - Geographic/spatial data that identifies a specific location on earth.

Geospatial - Relating to or denoting data that is associated with a particular location.

Google Earth – A virtual globe, map and geographical information program that maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and GIS 3D globe.

Naiban – Village leader.

Oziexplorer - A raster navigation and mapping software for Windows. It is very popular among off-road drivers and adventure travellers as it allows to use and create custom maps for remote locations that are not fully covered by major map providers.

Potamodromous - fish species whose migrations occur wholly within freshwater for breeding and other purposes.

Regulator – A gated structure that regulates the flow of water, usually into off-stream channels.

Rehabilitation – The process of restoring a structure, habitat or stream back to a condition of good condition or operation.

Road Crossing – Any structure that crosses a waterway to enable traffic to cross the waterway.

Shapefile - is a popular geospatial vector data format for geographic information system software. It is developed and regulated by Esri as a open specification for data interoperability among Esri and other GIS software products.

Spillway – A structure on a barrier that conveys water past the barrier.

Vector Data - A data model based on the representation of geographical objects by Cartesian co- ordinates, commonly used to represent linear features. Each feature is represented by a series of co- ordinates which define its shape, and which can have linked information.

Waterway – A river, stream, creek or channel

Waypoint - A set of coordinates that identify a point in physical space.

Weir – A barrier across a waterway that incorporates the spillway into the main body of the structure.

Acronyms

ACIAR – Australian Centre for International Agricultural Research

LMB – Lower Mekong Basin

MRC – Mekong River Commission

NGO – Non-government Organisation

O&M – Operation and maintenance

Lao P.D.R. – Lao Peoples Democratic Republic

References

Baran E, Ratner B. 2007. The Don Sahong Dam and Mekong Fisheries. A science brief, WorldFish Center.

Baumgartner, L. J, Marsden, T, Singhanouvong, D, Phonekhampheng, O, Stuart, I.G. and Thorncraft, G. 2012. Using an experimental in situ fishway to provide key design criteria for lateral fish passage in tropical rivers: A case study from the Mekong River, Central Lao PDR. River Research and Applications. Volume 28, Issue 8, pages 1217–1229

Hortle KG. 2007. Consumption and Yield of Fish and Other Aquatic Animals from the Lower Mekong Basin. Mekong River Commission: Vientiane.

Kemp P.S. and OHanley J.R. 2010. Procedures for evaluating and prioritising the removal of fish passage barriers: a synthesis. Fisheries Management and Ecology Volume 17, Issue 4, pages 297–322

Larinier, M. 2001. Environmental Issues, Dams and Fish Migration. In: Dams, Fish and Fisheries -Opportunities, challenges and conflict resolution. FAO Fisheries Technical Paper No. 419. Rome, FAO. 2001. 166p

Marsden et. al. 2014 *Prioritising Barriers to Upstream Fish Passage for remediation works. Xe Champhone Catchment*, Lao P.D.R. AFPS. 49p

Marsden et. al. 2015 *Prioritising Barriers to Upstream Fish Passage for remediation works. Nam Ngum Catchment*, Lao P.D.R. AFPS. 49p

Moore, M. and Marsden, T. 2008. Fitzroy Basin Fish Barrier Prioritisation Project. Queensland Dept Primary Industries and Fisheries. 49p

Osborne M. 2009. The Mekong: river under threat. Lowy Institute Paper 27. Double Bay, NSW, Australia, Lowy Institute for International Policy.

Sverdrup-Jensen S. 2002. Fisheries in the Lower Mekong Basin: Status and perspectives. MRC Technical Paper No. 6. Mekong River Commission, Phnom Penh, 84 pp.

Appendix 1: Example Prioritisation – Xe Champhone

Identification

Stage 1 of the Xe Champhone prioritisation process used a desktop computer installed with ArcMap 10.1 GIS software. To initially identify potential barriers raster data in the form of satellite imagery and aerial photography was used in ArcMap. Due to the poor imagery coverage across some areas of the Xe Champhone catchment, Google Earth imagery was also used. Vector data in the form of stream and road network shapefiles were then acquired from the Mekong River Commission (MRC). Vector data was then imported into both ArcMap and Google Earth to assist in identifying potential barriers.

Remote Assessment

The following attributes were assessed for each of the potential in-stream barriers identified in the first stage of the prioritisation process:

a. Type of stream or wetland on which the potential barrier is located;

b. Number of barriers located downstream;

c. Catchment condition of the surrounding catchment;

d. Available upstream habitat (amount of habitat opened up above the barrier to the next barrier or top of catchment if the barrier is remediated);

e. Location within the catchment.

A total of 798 potential in-stream barriers to fish migration were identified in the Xe Champhone catchment. An initial elimination process removed 243 potential barriers on small intermittent streams (stream order one) with minimal fishery value. This process left 555 potential barriers to be analysed further in stage one. The highest score achieved in stage one was 28 (Table 1). This was achieved by the first potential barrier located on the Xe Champhone upstream from the Mekong mainstream.

Table 1. Number of potential barriers at each scoring level from highest to lowest

Score	No. of potential barriers	Score	No. of potential barriers
28	1	21	5
27	5	20	2
26	2	19	7
25	4	18	3
24	2	17	6
23	2	16	2
22	6	15 or less	508

The highest ranked barriers were generally clustered around the lower Xe Champhone wetlands (Figure 1), however there were a number of barriers on main stream channels higher in the system that also ranked highly in the prioritisation.

Table 2. The top ten barriers in the Xe Champhone after stage 1 of the prioritisation.

BA Rank	Barrier ID	Stream name	Barrier Type
1	2328	Xe Xangxoy	Medium Weir
2	2343	Xe Xangxoy	Low Weir
3	75	H. Souy	Medium Weir
4	67	H. Makmi	Large Weir
5	77	H Souy (Anabrach)	Bund Wall & Regulator
6	76	H Souy (Anabrach)	Bund Wall & Regulator
7	215	H Salongkhiang	Dropboard Weir
8	32	H. Sala	Medium Weir
9	68	H. Makmi	Drop Board Weir
10	6005	Xe Champhone anabranch	Low weir

Field Appraisal

The field appraisal stage of the prioritisation process involved ground-truthing the top 105 priority ranked potential barriers after the remote assessment. The scope of the initial ground-truthing inventory was determined by the available staff resources, which limited the mapping to the top 105 sites. To achieve the appraisal a small team of qualified fisheries biologists and students from the National University of Laos used laptop computers installed with Oziexplorer mapping software and a Geographical Position System (GPS) tracking system. Potential barriers were located via mapping software and GPS, then accessed via a vehicle or on foot. Barrier status was then determined i.e. is it barrier or non barrier? Non barriers (ie those determined to have no impact on fish passage at any stage of the hydrograph) were removed from the process, while actual barriers were assessed further on a range of ecological, social and physical criteria.

Important barrier information gathered included; barrier dimensions, headwater and tailwater levels, access for heavy machinery, Naiban (village chief) support, observed fish species, structure owners, and importance to the community. Additional information such as the assessor's name, date of assessment, photos and video details, stream and barrier name, date and coordinates of the barrier were also recorded.

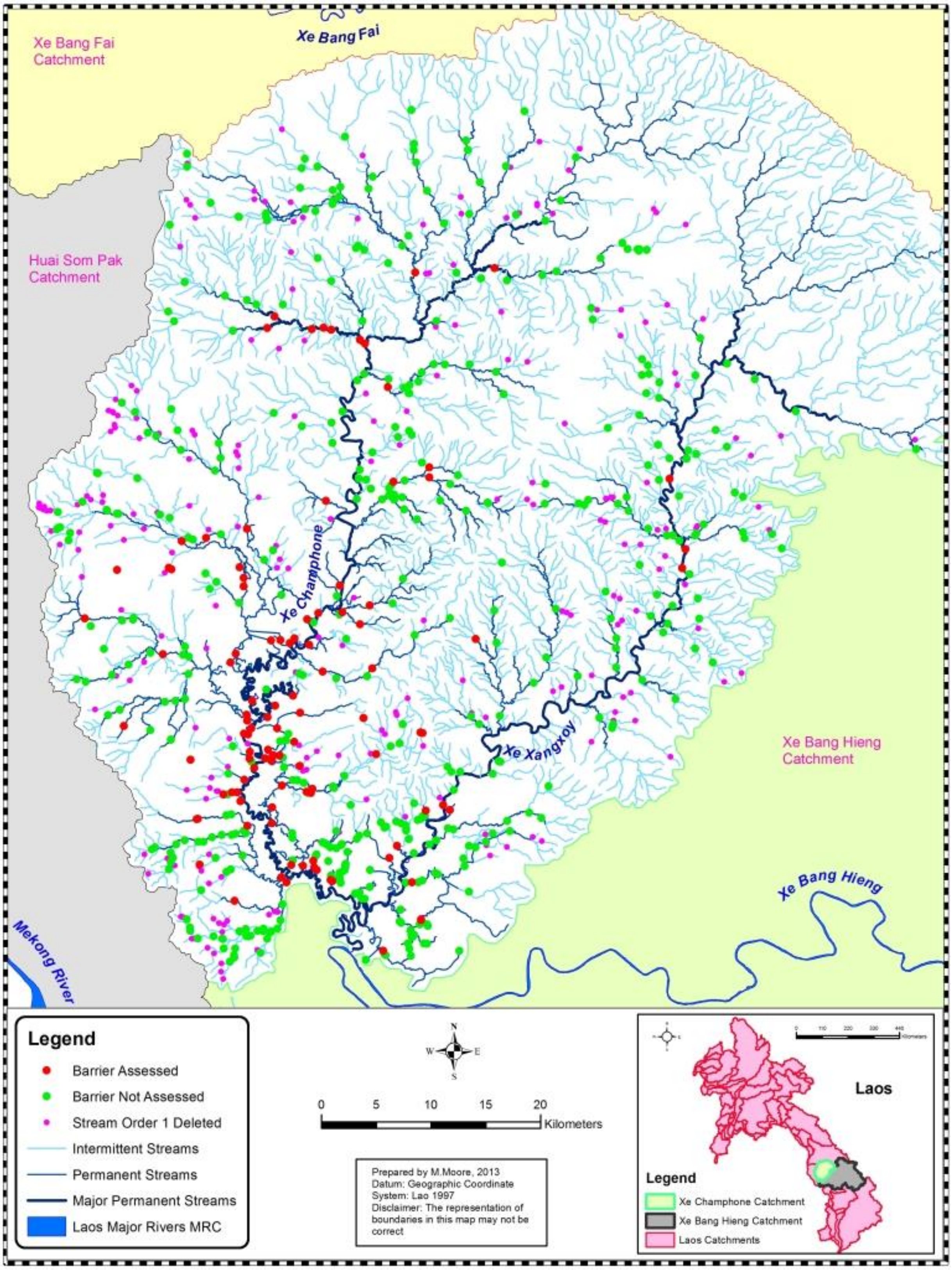


Figure 1. Location of all potential barriers in the Xe Champhone catchment. Pink dots indicate potential barriers deleted in the remote assessment due to inadequate habitat and small stream size. Green dots indicate a barrier that has been assessed but not visited as they are a low priority (450). While Red dots indicate a high priority barrier that has been field assessed (105).

Biological Assessment

For a biological assessment score, all barriers were assigned a score based on 'how well' they answered the criteria for each of a further five questions. All scores were collated and added to the remote assessment score to determine a refined list of barriers after the biological assessment. The following attributes are fundamental for in-stream barriers to score well in the biological assessment stage of the selection criteria process:

a. High transparency of the barrier to migrating fish

b. Stream with high quality catchment with excellent riparian condition,

c. Natural, permanent and non-polluted flow,

d. Diverse and abundant in-stream habitat,

e. Important site to local fishers

A total of 105 potential barriers were validated in the field during the biological assessment stage of the prioritisation. Of the validated potential barriers, 61 (59%) were identified as barriers to fish migration, while 43 potential barriers (41%) were field vaerified as non-barriers. The 61 barriers to fish migration were then priority ranked (Table 3 and Figure 2) in accordance with the ecological and physical criteria set out for the biological assessment, before advancing to socio-economic stage of the prioritisation process.

Table 3. The top 25 confirmed barriers and their rank in order of priority after Stage 2 of GIS Prioritisation process.

Stage 2 Rank	Barrier ID	Stream name	Barrier Type
1	2328	Xe Xangxoy	Medium Weir
2	2343	Xe Xangxoy	Low Weir
3	68	H. Makmi	Drop Board weir
4	6005	Xe Champhone anabranch	Low weir
5	75	H. Souy	Medium Weir
6	67	H. Makmi	High Weir
7	77	H. Souy (Anabrach)	Bund Wall & Regulator
8	2471	H. Thouat	High Dam
9	32	H. Sala	Medium Weir
10	6014	H. Payong	High Weir
11	51	Unnamed (near B. Toumgne)	Low Weir
12	79	H. Bak	Regulator
13	114	H. Kalang	Dropboard Weir
14	215	H. Salongkhiang	Dropboard Weir

15	80	H. Lat	Dropboard Weir
16	6112	Unnamed (near B. Bak)	Medium Weir
17	76	H. Souy (Anabrach)	Bund Wall & Regulator
18	2274	H. Pakho	Dropboard Weir
19	73	Wetland Sth B. Kengkok-Dong	Wetland Bund
20	43	H. Payong	Medium Weir
21	116	H. Kalang	Medium Weir
22	94	Unnamed (near B. Nongpham)	Wetland Bund
23	104	Unnamed (near B. Nongpham)	Wetland Bund
24	74	Unnamed (near B. Kengkok-Kang)	Wetland Bund
25	193	Unnamed (near B. Nongpham)	Wetland Bund

Socio-economic Assessment

The socio-economic assessment was the final stage of the barrier prioritisation process. It involved analysing the top 61 barriers after stage two of the process with a number of economic, social and technical criteria.

The following attributes were fundamental for in-stream barriers to score well in the socio-economic assessment stage of the selection criteria process:

a. Low cost to remediate barrier,

b. Simple fishway design with minimal engineering required,

c. Resultant highly effective fishway design that can pass many fish

d. Fisheries productivity gains across many villages,

Each of the 61 barriers were prioritised in accordance with the scoring system set out for stage three of the process. The end product of the prioritisation process is a priority list of the top 26 ranked barriers to fish passage in the Xe Champhone catchment requiring future remediation (Table 4 and Figure 3). The final ranking had a number of barriers with equal scores, as such the list of the top 26 barriers is grouped around these equal scores, hence the ranking can miss individual ranks.

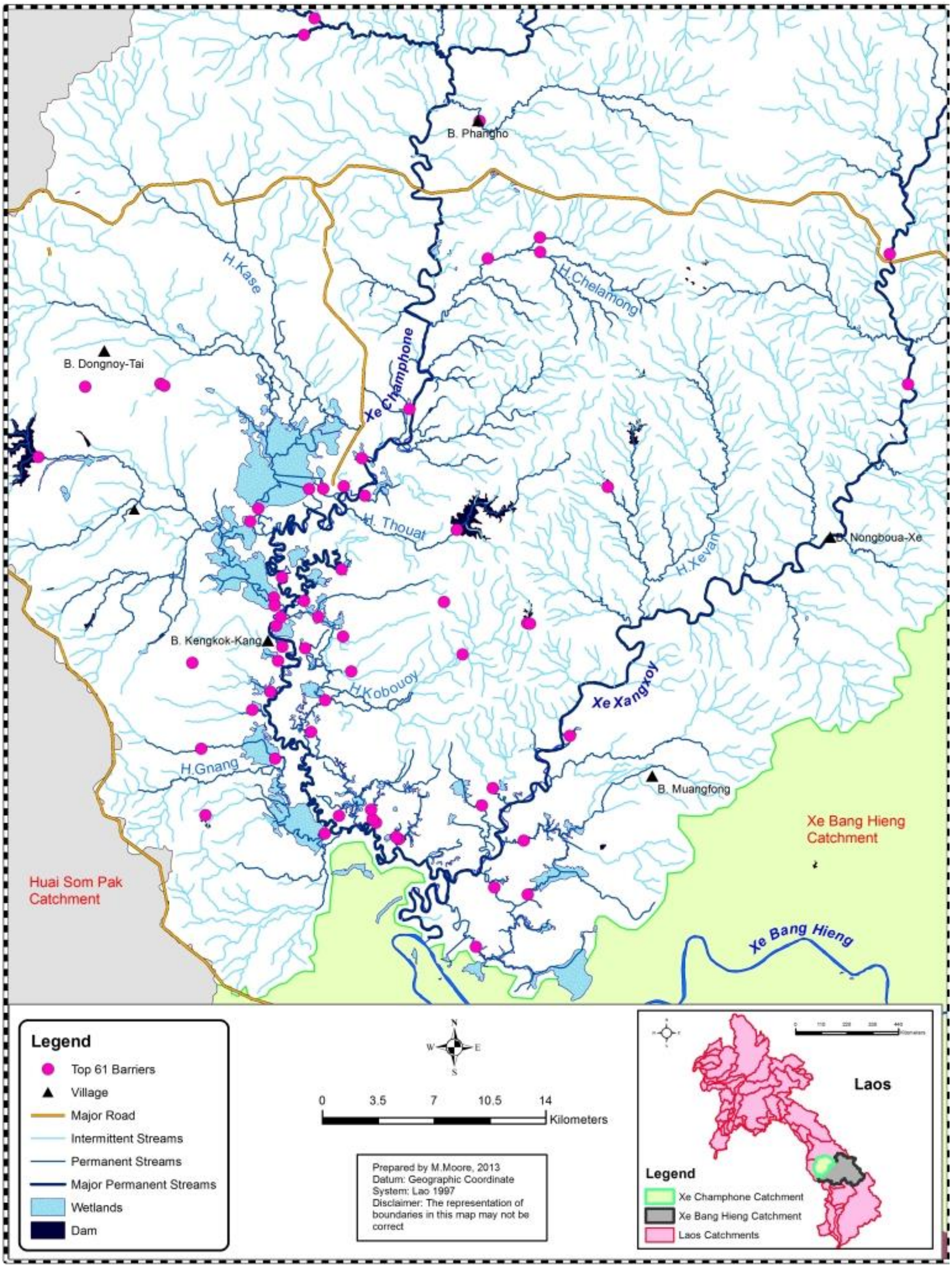


Figure 2. Location of the top 61 barriers for remediation, refined after stage 2 of the barrier prioritisation process.

Table 4. Final ranking for the top 26 priority barriers in the Xe Champhone.

Stage 3 Rank	Barrier ID	Stream name	Barrier Type
1	2328	Xe Xangxoy	Med Weir
1	2343	Xe Xangxoy	Low Weir
3	51	Unnamed (near B. Toumgne)	Low Weir
3	68	H. Makmi	Drop Board Weir
3	6005	Xe Champhone anabranch	Low weir
6	75	H. Souy	Med Weir
7	114	H. Kalang	Dropboard Weir
8	80	H. Lat	Dropboard Weir
8	215	H. Salongkhiang	Dropboard Weir
8	32	H. Sala	Med Weir
11	6112	Unnamed (near B. Bak)	Med Weir
11	6014	H. Payong	High Weir
11	67	H. Makmi	High Weir
14	73	Wetland Sth B. Kengkok-Dong	Wetland Bund
14	77	H. Souy (Anabrach)	Bund Wall & Regulator
16	116	H. Kalang	Med Weir
16	76	H. Souy (Anabrach)	Bund Wall & Regulator
16	79	H. Bak	Regulator
19	2274	H. Pakho	Dropboard Weir
20	43	H. Payong	Med Weir
20	2471	H. Thouat	High Dam
22	639	H. Chelamlong	Med Weir
22	193	Unnamed (near B. Nongpham)	Wetland Bund
22	91	Unnamed (near B. Nongpham)	Wetland Bund
22	74	Unnamed (near B. Kengkok-Kang)	Wetland Bund
22	94	Unnamed (near B. Nongpham)	Wetland Bund

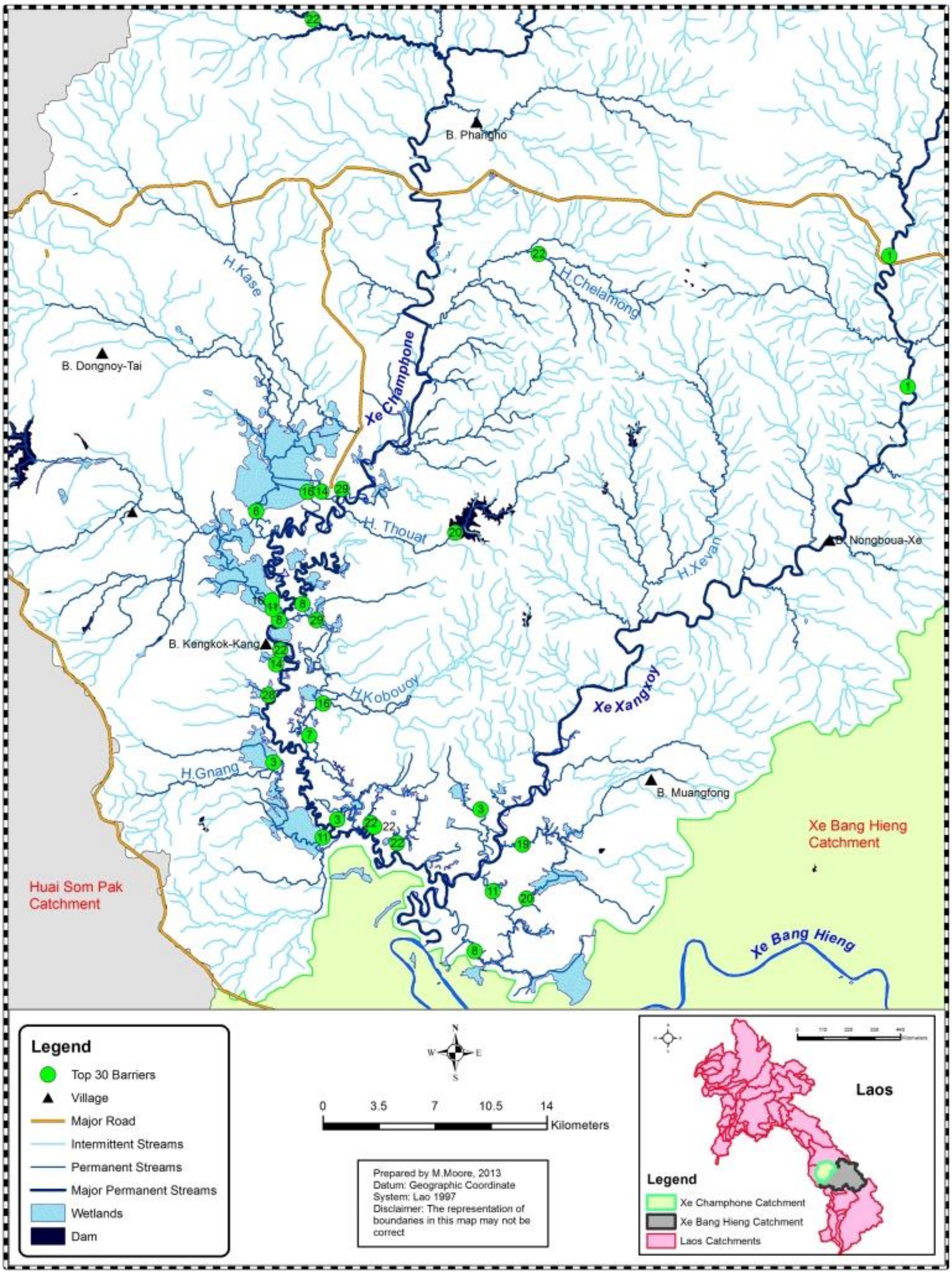


Figure 3. Final rank (inside barrier) and location of the top 26 barriers to fish migration in the Xe Champhone catchment for fish passage construction.

Top 26 barriers

Rank	**1**
Barrier Id number	2328
Stream Name	Xe Xangxoy
Barrier Type	Med Weir
Barrier Height	2.0m
Location	1.7km South Ban Nakang-Xe
Fishway Option	Vertical Slot Fishway
Approximate cost	$200,000.00

Rank	**1**
Barrier Id number	2343
Stream Name	Xe Xangxoy
Barrier Type	Low Weir
Barrier Height	1.3m
Location	500m west Ban Kalong-Nua 40km west of Normanton
Fishway Option	Vertical Slot Fishway
Approximate cost	$75,000.00

Rank	**3**
Barrier Id number	51
Stream Name	Unnamed (near B. Toumgne)
Barrier Type	Dropboard Weir
Barrier Height	1.8m
Location	2.7km South Ban Toumgne
Fishway Option	Vertical Slot Fishway
Approximate cost	$75 000.00

Rank	**3**
Barrier Id number	68
Stream Name	H. Makmi
Barrier Type	Regulator
Barrier Height	2.0m
Location	500m N.E. Ban Laomat
Fishway Option	Vertical Slot Fishway
Approximate cost	$75 000.00

Rank	**3**
Barrier Id number	6005
Stream Name	Xe Champhone anabranch
Barrier Type	Low weir
Barrier Height	1.3m
Location	5.2km S.W. Ban Naholouang
Fishway Option	Vertical Slot Fishway
Approximate cost	$75 000.00

Rank	**6**
Barrier Id number	75
Stream Name	H. Souy
Barrier Type	Med Weir
Barrier Height	2.5m
Location	1.2km N.E. Ban Dongneng
Fishway Option	Concrete cone Fishway
Approximate cost	$85 000.00

Rank	**7**
Barrier Id number	114
Stream Name	H. Kalang
Barrier Type	Dropboard Weir
Barrier Height	1.3m
Location	3.3km West Ban Phonkho
Fishway Option	Baffles
Approximate cost	$5 000.00

Rank	**8**
Barrier Id number	80
Stream Name	H. Lat
Barrier Type	Dropboard Weir
Barrier Height	1.3m
Location	2.0km East Ban Kengkok
Fishway Option	Baffles
Approximate cost	$5 000.00

Rank	**8**
Barrier Id number	215
Stream Name	H. Salongkhiang
Barrier Type	Dropboard Weir
Barrier Height	2.5m
Location	2.0km N.E Ban Kengkok
Fishway Option	Vertical Slot Fishway
Approximate cost	$150 000.00

Rank	**8**
Barrier Id number	32
Stream Name	H. Sala
Barrier Type	Med Weir
Barrier Height	1.5m
Location	2.4km N.E. Ban Songkhon
Fishway Option	Vertical Slot Fishway
Approximate cost	$75,000.00

Rank	**11**
Barrier Id number	6112
Stream Name	Unnamed (near B. Bak)
Barrier Type	Med weir
Barrier Height	1.5m
Location	1km North Ban Kengkok
Fishway Option	Concrete cone Fishway
Approximate cost	$100,000.00

Rank	**11**
Barrier Id number	6014
Stream Name	H. Payong
Barrier Type	High Weir
Barrier Height	3.3m
Location	4.5km N.E of Ban Donsavang
Fishway Option	Concrete cone Fishway
Approximate cost	$150,000.00

Rank	**11**
Barrier Id number	67
Stream Name	H. Makmi
Barrier Type	High Weir
Barrier Height	3.5m
Location	3.6km N.E. Ban Khoklo
Fishway Option	Concrete cone Fishway
Approximate cost	$150,000.00

Rank	**14**
Barrier Id number	73
Stream Name	Wetland Sth B. Kengkok-Dong
Barrier Type	Wetland Bund
Barrier Height	0.8m
Location	1km Sth Ban Kengkok
Fishway Option	Rock Ramp Fishway
Approximate cost	$10,000.00

Rank	**14**
Barrier Id number	77
Stream Name	H. Souy (Anabrach)
Barrier Type	Bund Wall & Regulator
Barrier Height	3.0m
Location	800m West Ban Xakhun
Fishway Option	Concrete cone Fishway
Approximate cost	$150,000.00

Rank	**16**
Barrier Id number	116
Stream Name	H. Kalang
Barrier Type	Med Weir
Barrier Height	1.8m
Location	2.5km S.W. Ban Taleo
Fishway Option	Concrete cone Fishway
Approximate cost	$45 000.00

Rank	**16**
Barrier Id number	76
Stream Name	H. Souy (Anabrach)
Barrier Type	Bund Wall & Regulator
Barrier Height	4.0m
Location	1.4km West Ban Xakhun
Fishway Option	Concrete cone Fishway
Approximate cost	$150,000.00

Rank	**16**
Barrier Id number	79
Stream Name	H. Bak
Barrier Type	Regulator
Barrier Height	5.0m
Location	1.6km North Ban Kengkok
Fishway Option	Vertical Slot Fishway
Approximate cost	$150,000.00

Rank	**19**
Barrier Id number	2274
Stream Name	H. Pakho
Barrier Type	Drop Board Weir
Barrier Height	2.8m
Location	3.2km South Ban Pasit
Fishway Option	Concrete cone Fishway
Approximate cost	$150,000.00

Rank	**20**
Barrier Id number	43
Stream Name	H. Payong
Barrier Type	Med Weir
Barrier Height	3.5m
Location	6.7km N.E. Ban Dongsavang
Fishway Option	Concrete cone Fishway
Approximate cost	$150,000.00

Rank	**20**
Barrier Id number	2471
Stream Name	H. Thouat
Barrier Type	High Dam
Barrier Height	20.0m
Location	4.4km East Ban Thuat
Fishway Option	Concrete cone Fishway
Approximate cost	$450,000.00

Rank	**22**
Barrier Id number	639
Stream Name	H. Chelamong
Barrier Type	Med Weir
Barrier Height	2.2m
Location	2.8km East Ban Chelamong
Fishway Option	Concrete cone Fishway
Approximate cost	$100,000.00

Rank	**22**
Barrier Id number	193
Stream Name	Unnamed (near B. Nongpham
Barrier Type	Wetland Bund
Barrier Height	4.0m
Location	4.5km S.W. Ban Nongpham
Fishway Option	Concrete cone Fishway
Approximate cost	$200,000.00

Rank	**22**
Barrier Id number	91
Stream Name	Unnamed (near B. Nongpham)
Barrier Type	Wetland Bund
Barrier Height	2.5m
Location	4.5km S.W. Ban Nongpham
Fishway Option	Concrete cone Fishway
Approximate cost	$100,000.00

Rank	**22**
Barrier Id number	74
Stream Name	Unnamed (near B. Kengkok-Kang)
Barrier Type	Wetland Bund
Barrier Height	1.2m
Location	500m South Ban Kengkok
Fishway Option	Rock Ramp Fishway
Approximate cost	$10,000.00

Rank	**22**
Barrier Id number	94
Stream Name	Unnamed (near B. Nongpham)
Barrier Type	Wetland Bund
Barrier Height	3.0m
Location	4.5km S.W. Ban Nongpham
Fishway Option	Concrete cone Fishway
Approximate cost	$100,000.00

Reporting

The reporting for the prioritisation within the Xe Champhone was completed in the form of a report that detailed the assessment process and outlined the methods, results and also detailed the structures that were of highest priority (Marsden et. al. 2014 *Prioritising Barriers to Upstream Fish Passage for remediation works. Xe Champhone Catchment*, Lao P.D.R.). This report was well received by local government and NGO's and has led to some of the barriers on the priority list being investigated for remediation. Plans have been drawn up for the installation of a fishway on the H. Souy which was ranked at Number 6 on the list, but will provide a high profile demonstration site due to its proximity to a large number of villages and its popular status as a recreation location.

Design

The design of fish passage at the H. Souy weir have been conducted in conjunction with the funding body, the World bank. This process has seen several visits to the site, as well as sites surveys and a design process the has involved engineers, biologists and local agriculture and irrigation officials. The conept that is currently in the detailed design phase is a dual bank cone fishway that will provide fish passage over the majority of flows encountered at the site (Figure 44).

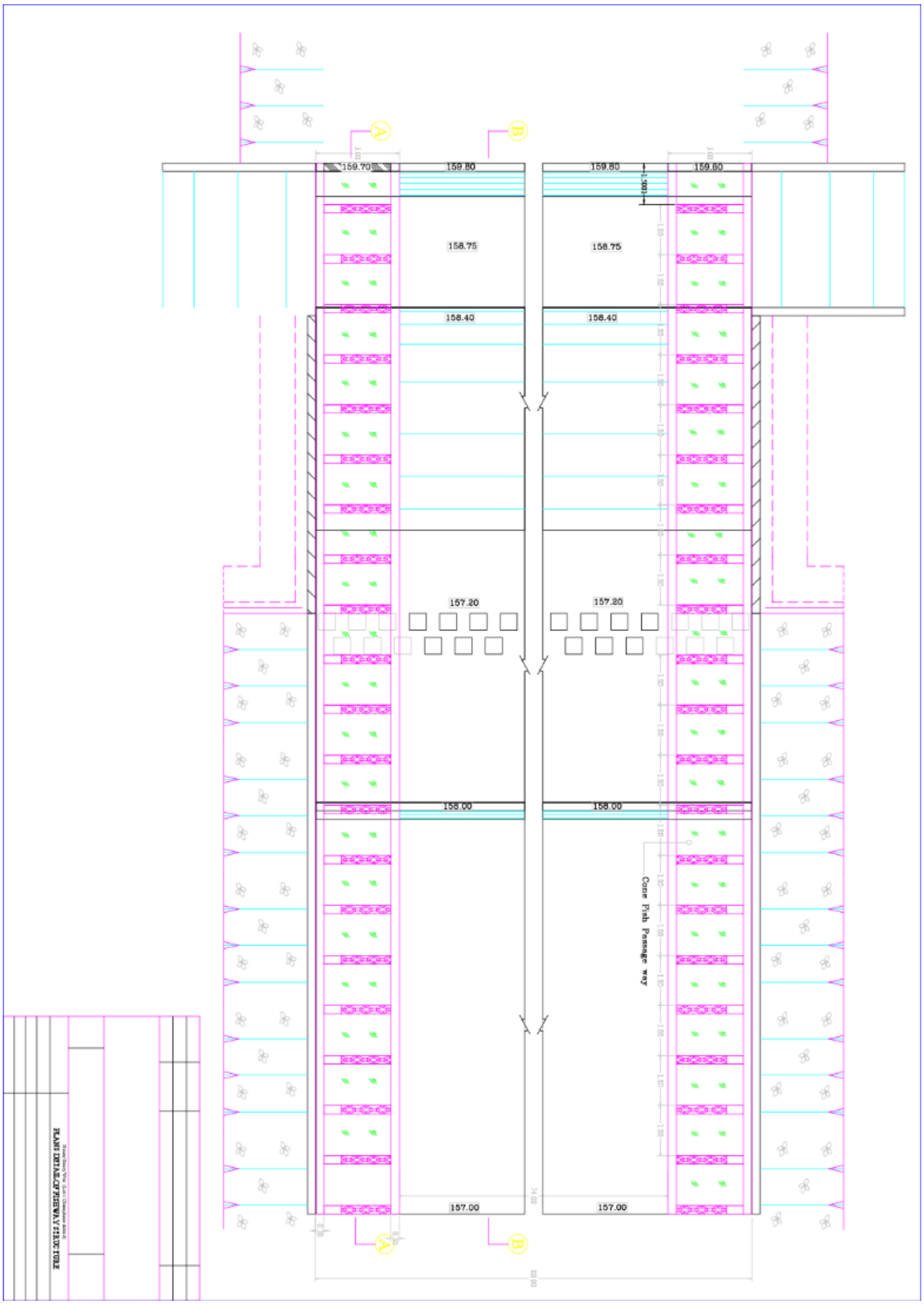


Figure 44. Design drawing for a cone fishway for the main weir on the H.Souy.

Appendix 2: Optimising fish-friendly criteria for incorporation into the design of mini-hydro schemes in the Lower Mekong Basin

Garry Thorncraft, Oudom Phonekhampheng, Lee Baumgartner, Kate Martin, Brett Pflugrath, Rich Brown, Daniel (Zhiqun) Deng, Craig Boys, and Anna Navarro

***Challenge Program for Food and Water Project (MK15)* December 2013**

5.4.4. General Fish passage design requirements

River development in the Lower Mekong Basin has led to construction of numerous dams, weirs and other water regulation devices which limit migratory fish movements (technically referred to as fish passage). Fish passage is important because all freshwater fish need to move within or among their habitats as part of their natural life cycle. Movements of fish between rivers and floodplains are subsequently restricted by these barriers. In many areas of the world, this has resulted in severe declines in fish populations. Where dams, weirs and other water regulation devices are present:

1. Fish may not spawn;
2. Juvenile fish populations cannot disperse to nursery grounds or new habitats;
3. Localised movement of fish is restricted;
4. The genetic diversity of fish populations decreases; and
5. The threat of predators or disease increases if fish accumulate below barriers.

Fisheries agencies often construct fishways (commonly known as fish ladders) to help fish complete movements past migration barriers. A fishway is basically an open channel, with low flows and low turbulence that allows fish to swim through a migratory obstruction. Many types of fishways have been developed in many areas of the world and have helped to rehabilitate fish populations. However, to ensure maximum effectiveness it is important that fishways are designed for local species. Many fish have different swimming abilities, some prefer fast water, some prefer slow. Understanding how fish respond to different flow environments is therefore an important step in designing a useful and effective fishway. To ensure fishways are fully effective, scientists usually perform in-field experiments with migrating fish to learn about swimming abilities and ensure fishway operation is optimised. The fishway design most applicable to any particular situation is largely determined by site-specific issues and fish community composition. Various types of fishways are implemented worldwide including:

Bypass or nature-like fishways:

Bypass fishways consist of a low-gradient earthen channel that mimics natural streams using a series of ponds and small flow control structures in a narrow channel that bypasses the dam or weir. The flow control structures within the channel can consist of rock or pre-cast concrete baffles often referred to as cones. In Europe, bypass fishways have been successfully used to provide passage past barriers for many fish species and sizes.

Denil fishways

Denil fishways are steeper channels where water flow is controlled by closely spaced U-shaped baffles. Resting pools are included for fish on their migration up Denil fishways greater than 1 metre in height. The Denil design allows steeper channels to be used than in vertical-slot designs because they are hydraulically efficient, resulting in shorter and cheaper fishways.

Vertical slot fishways

Vertical-slot fishways are suited to barriers up to 6 metres in height to work effectively. This fishway type consists of a channel divided into a series of pools by baffles. The baffles reduce water velocity and turbulence and allow fish to pass in either high or low river flow conditions. The slope of the channel and distance between each slot control the water velocity, therefore, the fishway can be designed to suit the swimming ability of particular ascending fish.

Rock-ramp fishway

Rock-ramp fishways can be used to allow fish passage over low weirs, generally less than 4 metres in height. The fishway is designed to simulate natural stream pools and falls, or rifles. This design can be very cost effective and be constructed with limited resources.

Cone fishway

A cone fishway is a modified version of a rock ramp fishway. Rather than containing rocks to simulate natural falls or riffles, it is substituted for a pre-fabricated cone which is made from concrete. The solution is very practical because concrete is often cheaper than sourcing and transporting natural rocks. Hydraulically, the two fishways perform in a similar manner.

Fish Lock or Lift

A fishlock operates in a similar manner to a navigation lock for boats. Fish enter a chamber via a downstream gate which closes after a specified period of time. The water level then equilibrates with that of the weirpool/dam. An exit gate opens and fish can then exit the lock and continue their migration. Some locks may include a rising floor which can lift the lift to the dam surface. Fish locks and lifts have high capital costs and moving parts that require ongoing maintenance. They are most suited to large barriers. Various aspects of fishway design are important to optimise effectiveness. These need to be considered during the design phase of hydro projects and advised by suitably qualified engineers in collaboration with biologists which have an understanding of local species ecology. Main design aspects which will require specialist advice include:

Entrance location

After design, the entrance location is the single most important design aspect that can lead to fishway failure. The main reason for this is that if fish cannot locate the fishway entrance, they will certainly not be able to ascend the fishway. The entrance location must be located at the upstream limit of migration at any given site. Locating an entrance too far downstream will mean some fish will move upstream past the entrance and miss it. Likewise, if it is located too far upstream fish may not be able to reach it. Multiple entrances may be required at some sites where fish are seen to accumulate at several different locations.

Exit location

The location of the fishway exit is of importance when dealing with hydropower sites. The exit must be located at a sufficient distance from the forebay to ensure that fish are not simply drawn into the turbine or back over the spillway once they have exited the fishway. The problem was highlighted at a mainstem dam on the Murray River, Australia (Stuart*, et al.* 2010). Some confusion among velocity profiles during the design phase led to an inappropriate exit location. Fish exiting the fishway were confronted with excessive velocities and entrained into the turbine. The only way to mitigate the problem was to construct a stainless steel extension to ensure fish were outside the high velocity zone.

Resting pools

Fishways that require long channels may require resting pools so that fish are not required to make a large sustained ascent that may lead to fatigue. Resting pools are standard for fishways constructed in Australia (Mallen-Cooper 2000). In general, resting pools are provided after fish have ascended a vertical metre in height. Resting pools are generally 2.5 times the standard pool volume (Mallen-Cooper 2000) but this criteria may be different for Mekong species.

Bottom rocks

Some fishways are constructed with rocks fitted to the fishway floor to aid in the passage of crustaceans which may find it difficult to move on smooth concrete (Barrett and Mallen-Cooper 2006). Macrobrachium is an important freshwater prawn species in the Lower Mekong Basin and should be considered as a target species at sites where passage may be obstructed. The provision of either rocks or increased floor roughness through exposed aggregate can be a useful way to enhance passage.

Gradient and headloss

Fishway floor slope is a critical design criteria. Floor slope determines the overall headloss (water level drop) between fishway pools, governs maximum velocity and influences turbulence. Many fish have critical velocity thresholds that they can sustain for any given period of time (Domenici and Blake 1997). It is essential that floor slope reflects swimming ability of target species. If velocities are too high, then some species may not be able to ascend. Likewise, turbulence is a critical factor influencing fishway success in France (Tarrade*, et al.* 2008). Designers need to understand the impact of floor slope on generating turbulence which exceeds tolerable limits for target species (Liu*, et al.* 2006). Biologists and engineers need to carefully consider optimising floor slope during the design phase to ensure velocities and turbulence match hydraulic needs of target species.

Operating range

A critical fishway design element is the operating range. Optimal fishway operation relies on the entrance location, velocities and turbulence suiting local species over the full range of flows experienced at a site. For instance, the Mekong River can vary in level up to 13m in a single year. A fishway designed with an entrance that was only suited to a 2m river rise would not work for the full complement of flows. As tailwater increases, the entrance will become drowned and water will advance through the fishway. The advancing water will drown baffles, decrease velocity and reduce the ability to attract fish to the entrance. The overall impact on fishway operation is reduced efficiency during high levels.

Understanding the hydrology of the target site is therefore critical to effective fishway operation. The maximum water level variation must be understood and then used to inform fishway design. It is therefore imperative that entrance location, attraction flow and internal hydraulics work for the full range of expected flows. If hydrological data are scant (as they will be in many parts of the Lower Mekong Basin), then provincial and district fisheries officers should be consulted and encouraged to provide this information during the design phase. Including local knowledge is an excellent mechanism to ensure informed decisions are made in the absence of reliable gauge data.

Effective operating life

Wherever possible, the effective life of a fishway should be equal or greater than the expected life of the structure it has been fitted to. Determining the effective fishway operation life can, however, vastly influence construction cost. Fishways with lower quality and constructed of more perishable materials are generally cheaper to construct. However, maintenance costs can be higher and there will be a need to replace the full structure once the effective life has expired. Fishways with a longer life will require higher quality materials and have an increased capital construction cost. But maintenance costs can be lower and the need to forward budget a replacement is reduced. In some instances, using higher quality materials can lead to theft, especially at unmanned structures, but this risk would need to be determined and managed during the design and construction phase.

Fishway cover

Designing fishways for large operating ranges can lead to high walls which have large vertical distances between the top of channel and water. International construction standards would require either the walls to be fenced, or the installation of gridmesh to prevent the risk of death or injury to the general public. The provision of gridmesh can introduce an additional hazard. In some areas of the Lower Mekong Basin, children may enter the fishway to either catch fish or to explore. Gridmesh can prevent people within the fishway from escaping. This risk can be minimised by including manholes, access points and ladders recessed into channel walls. Each site, however, will be different and the need for gridmesh and access points will be determined by the fishway operating range, channel height and ease of accessibility.

Appendix 3: Improving Fish Passage in the Mekong and Murray Darling Basins

AN AUSTRALIAN-LAO COLLABORATION

Improving fish passage in the

Mekong and **Murray-Darling Basins**

- AUSTRALIAN GOVERNMENT
  —AUSTRALIAN CENTRE FOR INTERNATIONAL AGRICULTURAL RESEARCH
- NATIONAL AGRICULTURAL AND FORESTRY RESEARCH INSTITUTE
  —LIVING AQUATIC RESOURCES RESEARCH CENTRE (LARReC)
- NATIONAL UNIVERSITY OF LAOS
- QUEENSLAND DEPARTMENT OF AGRICULTURE, FISHERIES AND FORESTRY
- CHARLES STURT UNIVERSITY
- NSW DEPARTMENT OF PRIMARY INDUSTRIES (FISHERIES)

BACKGROUND

The Murray-Darling and the Mekong Rivers are two of the world's major catchment systems. They drain similar catchment areas, are both over 4000 km in total length and support over 60 million people combined. Both systems contain unique fish communities which are important sources of biodiversity, food security and recreational opportunities. The Murray-Darling Basin, for instance, has an active recreational fishery estimated to be worth between A$75–100 million annually. The Mekong River, by comparison, supports an annual capture fishery of about two million tonnes with a first-sale value between US$2000–4000 million per year. This equates to approximately 2% of the total world marine and freshwater fin fish catch.

THE PROBLEM

Development projects in both Australia and the lower Mekong region has led to construction of numerous water regulation devices (over 10 000 in both countries) which limit migratory fish movement. Movements of fish (and other aquatic animals) between rivers and floodplains may be entirely prevented, and this has led to severe declines in fish production in many areas. Fish need to move to a range of locations within a stream, creek or river to reproduce, feed, disperse; form new territories and avoid predators. These movements can be small, occurring within small stretches of river or large, occurring over thousands of kilometres. A common form of small-scale movements, termed lateral migrations, occur when fish move between the main river channel and floodplain habitat during high flows. These movements are extremely important for fish to access nursery habitat or for feeding. Blocking these migrations can lead to declines if juvenile fish do not have opportunities to grow and disperse to new habitats. Protecting these migrations is therefore the main focus of current research activities in both the Mekong and Murray-Darling Basins.

THE SOLUTION

Fisheries agencies often construct fishways (commonly known as fish ladders) to help fish complete movements past migration barriers. A fishway is basically an open channel, with low flows and low turbulence that allow fish to swim through a migratory obstruction. Many types of fishways have been developed in many areas of the world and have helped to rehabilitate fish populations. However, to ensure maximum effectiveness it is important that fishways are designed for local species. Many fish have different swimming abilities, some prefer fast water, some prefer slow. Understanding how fish respond to different flow environments is therefore an important step in designing a useful an effective fishway. To ensure fishways are fully effective, scientists usually perform in-field experiments with migrating fish to learn about swimming abilities and ensure fishway operation is optimised.

DETERMINING EFFECTIVENESS

Determining the effectiveness of new fishways is essential to make sure fish are gaining benefit. Researchers are presently performing a series of experiments, in both Lao PDR and Australia, to measure fishway success for local species.

THE EXPERIMENTS AIM TO:

1. Determine species and size classes using the fishway

Scientists will directly trap the fishway to determine whether all species and size classes of fish are completing migrations. The structure of fish populations accumulating below the dam will be compared with those passing through the fishway to make sure that all species and size classes that are trying to migrate upstream are able to migrate. If there are no differences it is a good sign that the fishway is providing passage for all migratory fish.

2. Assess improvements to catch rates

It is important that any improved fish passage actually increases the number of fish upstream of a barrier. Catch rates from fishermen are therefore a good guide to determine if the fishway is working as expected. Catch rates of fishermen will be compared before and after fishway construction to assess how much improvement has occurred.

3. Identify potential areas to improve fishway design

Different fish species can have completely different swimming abilities. So it is often revealed that no single fishway can provide passage for all species and size classes as a site. Scientists are therefore constantly interested in determining limitations of technology and improving future designs. This is achieved by operating the fishway under a range of flow conditions and determining which species can and cannot ascend. Scientists then focus on species that cannot ascend and identify potential solutions through experimentation.

1 Lao woman fishing near fishway experimental site. **2** Recreational fisher on the Murray River. **3** Fishermen's catch at experimental site. **4 and 5** Lao fish migration barriers. **6** Setting up an experimental fishway. **7** Local village staff checking fishway assessment trap. **8** Experimental vertical slot fishway in operation. **9** University technician recording fish catch from experiment. **10 and 11** Identifying, then processing fish caught from the experimental fishway.

WHAT FISH WILL USE FISH LADDERS?

The ultimate aim of any fish ladder is to provide passage for all species and size classes of fish. However, this is difficult to achieve and each fishway is designed for local species that can be expected to use it upon completion. In Australia, fishways are regularly constructed for fish between 30 mm and 1200 mm. This encompasses most of the migratory community. In the Lower Mekong, providing fish passage at wetland regulators is aimed at small-bodied species and juvenile large-bodied species that need to access wetland nursery habitats. These fish are commonly less than 600 mm. However, scientists are interested in providing passage for large fish as well, and options to permit spawning migrations of fish between 600 mm and 1000 mm are currently being explored.

WHO IS INVOLVED?

The project is a bilateral collaboration between Australia and Lao PDR and incorporates many different agencies. Key Australian partners are NSW Department of Primary Industries (Fisheries); Queensland Department of Agriculture, Fisheries and Forestry; Charles Sturt University; and the Australian Centre for International Agricultural Research. Main Lao partners are Living Aquatic Resources Research Centre and the National University of Lao.

FURTHER INFORMATION

Dr Lee Baumgartner, Senior Research Scientist,
Narrandera Fisheries Centre
NSW Department of Primary Industries, Australia
lee.baumgartner@dpi.nsw.gov.au
www.dpi.nsw.gov.au

Dr Oudom Phonekhampheng, Dean of Science,
National University of Lao
oudomg@yahoo.com

Mr Douangkham Singhanouvong,
Head of Capture Fisheries, Living Aquatic Resources Research Centre, Lao PDR
douangkham_s@yahoo.co.uk

1 National University of Lao students conducting socio-economic survey with fishermen on catch rates. **2** Lao staff mapping barriers to fish migration. **3** NSW DPI technician testing water quality. **4** NSW DPI and Lao scientists. **5** Representatives from National University of Lao, Charles Sturt University, NSW DPI, and LARReC. FRONT COVER: Lock 3 fishway, Murray River. Lao University student with NSW DPI technician. Lao woman fishing.

ACIAR Project FIS/2009/041

Development of fish passage technology to increase fisheries production in the Lower Mekong and Murray-Darling Basins

Australian Government
Australian Centre for International Agricultural Research

LARReC

Queensland Government

Charles Sturt University

NSW Department of Primary Industries

NSWDPI 11368_AUG2012
Printed on FSC certified stock.

For further information contact:

Tim Marsden
Principal Consultant
Australasian Fish Passage Services
www.ausfishpassage.com
tim.marsden@ausfishpassage.com
Ph: (+61) 419724462