

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

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## Executive Summary

### Need for this report

Potentially one of the greatest threats to fish fauna in the Mekong region is the rapid expansion of infrastructure on major and tributary streams. Many new infrastructure projects are also being considered for small-scale hydropower. About 20% of the world's electricity is currently generated by hydropower and it is becoming the fastest growing renewable energy source. The total estimated hydropower potential of the lower Mekong River basin is 30 GW, which includes both large and small installations. Currently, 14 main-stem dams are planned for the Mekong River alone and hundreds of smaller units are planned for tributary streams and floodplain wetlands. Hydropower developments of any size have economic and livelihood benefits but can also lead to potentially damaging social and environmental impacts. Operating of hydropower units can substantially alter the hydrology and ecology of river systems. The disruption of critical upstream and downstream fish migrations is also recognized as a major ecological impact of hydropower developments.

Most work on the effects of hydropower development on fish has been based on North American salmonids at high head installations. Salmonid research has focused on both upstream and downstream effects. Many measures to mitigate environmental impacts have been subsequently developed. There is mounting evidence to suggest that salmonid focused techniques cannot be readily applied to other species which have different biological and physiological requirements. Furthermore, design criteria for high head dams may not be applicable at low head sites. Criteria to mitigate the impact of hydro developments must be developed specifically for local species. Few Mekong species exist outside the basin, which makes it particularly difficult to obtain hard data to inform hydro unit design.

The MK15 Challenge Program for Water and Food sought to address key knowledge gaps for Lower Mekong fish species by specifically acquiring research infrastructure within the Mekong region to set design criteria for small hydro installations. The National University of Laos was commissioned to procure key technology and perform pilot studies on Mekong species to determine whether data to inform hydro design could be generated. The team were also tasked with preparing good practice guidelines to minimise the impacts of small hydro development on fish. Finally, a small team of developers performed a pre-feasibility study on a small hydro project in the Nam Ngum catchment (Lao PDR). Each of these four tasks will help to address key knowledge gaps preventing the proliferation of small hydro in the Lower Mekong Basin. Information will be of interest to river managers and potential developers considering minimising potential fish-related impacts of future mini hydro projects.

### Susceptibility of selected species to injury from fluid shear stress

Fluid shear arises when two bodies of water, travelling at different velocities, intersect. Fish entrained at the interface of these two water masses will experience shear stress but the magnitude is dependent on waterbody mass and velocity and entrained fish body size. High shear occurs where rapidly flowing water passes near spillways, across screens and within turbine draft tubes. Shear stress can have harmful effects on fish but can be reduced through improved turbine design or modified operational practices.

A transparent cylindrical plexiglass flume (1.95 m long and 0.44 m diameter) was used to determine critical tolerances of silver shark (*Balantiocheilos melanopterus*) to different shear stress rates. A closed circular system was used and water was circulated using an electric pump. The flume was

connected at one end to a fibreglass reservoir. The remaining circuit was completed using a 15 cm diameter PVC pipe. On entry to the cylindrical flume, a conical plastic nozzle was installed to reduce the diameter flow from 15 cm to 5 cm. The restriction caused by this reduction created a high velocity submerged jet when the pump was operated. Fish were exposed to the high velocity jet, which simulated a high shear environment which may be experienced during turbine passage.

Data suggested that fish experienced higher levels of injury and mortality with increasing shear. The probability of mortal injury was minimal at shear stresses less than 400/s. The data demonstrated that excessive shear forces can have damaging impacts on fish. Levels of shear higher than those tested in this study will cause some degree of mortality in Silver shark. It is important to apply the precautionary principle in any hydro design. Therefore, developers should attempt to model potential shear profiles expected during turbine passage in selected designs. These data will be critical to determine potential impacts on fish. If the likelihood of adverse impact is high, then alternative designs which have lower shear stress should be explored.

### **Susceptibility of selected species to injury from pressure changes**

Fish that experience a rapid pressure change may experience barotrauma. Whether barotrauma represents substantial welfare concern depends on critical thresholds tolerable by fish and the ratio of pressure change. Barotrauma is commonly seen from fish that have passed through a turbine. Whilst shear stress and physical strike may impact some fish that pass through a turbine, all fish will experience some degree of pressure change. The magnitude of decompression during turbine passage is dependent upon the turbine runner design, the operation of the turbine, the submergence of the turbine runner (i.e., elevation of the turbine runner relative to the downstream water surface elevation), the total project head (difference between upstream and downstream water surface elevations) and the flow path. So once critical thresholds for fish are known, application to hydro design and construction will be possible.

To obtain data on Mekong species that could be used to inform improved hydro design, a series of barometric chambers were designed and constructed in the USA and shipped to Lao PDR. Units were installed at the National University of Laos and a pilot study initiated. Applicability of these approaches to the Lower Mekong was done using two commonly-available hatchery species, snakehead and Pa soi. Pilot scale research was done to gain a rough idea of the types of barotrauma injuries that may occur in Mekong species and begin to understand the variability in injuries among fish species. Outcomes of the pilot will be used to inform a larger study on the impacts of pressure-related injury for other species in the Mekong Basin. These were initial preliminary experiments which did not necessarily replicate all of the conditions of passing a hydro turbine or other water infrastructure. These experiments should, however, provide a good comparison of the effects of decompression on two fish species.

During experiments, fish were kept at atmospheric pressure (14 psia) for two hours then decompressed to pressures between approximately 1 and 2 psia, then returned to surface pressure. A total of 100 fish were successfully exposed to decompression and of those, 24 Snakehead died while 3 Pa Soi died, all during the 48h post experimental observation period. All Pa Soi survived control conditions, while 6 control snakehead died. There was some evidence of delayed mortality among both treatment and control fish. Immediate mortality doubled during the post experimental observation period in decompressed snakehead, but not the control.

Experiments successfully demonstrated that barotrauma is a concern among two Lower Mekong species following decompression. There were substantial differences in the biological tolerances of the two species. Snakeheads were far more intolerable to pressure changes than Pa Soi. Major differences in pressure change tolerances could be expected among different species and sizes of fish. There are many physoclistous species throughout the Mekong, and there is presently no information regarding tolerances to pressure change. It is therefore presently difficult to consider potential impacts on these species when designing small hydro developments.

Understanding the impacts of rapid decompression on fish have substantial implications for hydropower and regulator design because 1) physical laws govern the behaviour of gases under pressure; 2) Most fish have gas filled structures and 3) All fish that pass through a turbine will experience some degree of pressure change. Exposure to pressures below surface pressure (14 psia) was determined to be damaging to both species assessed. Developers should be encouraged to ensure the required pressure differential to maximise energy generation also protects migrating fish. We encourage engineers, managers, and scientists to work together to develop turbine and infrastructure designs that can apply critical pressure limits to reduce damage to fish while also attain reasonable levels of power generation, turbine efficiency and a broad head range (Brown et al. 2012). Critical pressure thresholds can also be used to optimize turbine operations for safe fish passage.

Given the high potential for mortality observed in only two species studied here, our work suggests that pressure change should be a primary factor considered during the small hydro plant design phase. Due to very visible differences in vulnerability to barotrauma, it is suggested that pressure limit criteria based on a small number of fish should not be deemed to adequately represent that of all Mekong River fish.

We also suggest that future effort be made to increase the capabilities of the NUOL barotrauma facilities. To replicate a wide range of turbine passages (where pressure rates of change can range from 200 to 900 PSI per second), the current chambers will need to be upgraded or a new system will need to be constructed. This is critical because the rate of pressure change plays a key role in the damage that occurs to fish when they pass through turbines.

These experiments were a critical first step forward to understanding how pressure change can influence Mekong species. However, a great deal more research is needed to ensure future hydro development can be done in a sustainable manner.

### **Good practice guidelines for mini hydro in the Lower Mekong Basin**

Nearly 30% of the world's population has no access to electricity. Most energy generation is based on fossil fuels and account for a significant proportion of gas emissions that have been linked to climate change. Hydropower is a major renewable energy source that can help global communities to meet sustainability objectives. Many countries recognise the need for hydropower of all scales to increase the overall contribution of renewable energy at a global scale. There is general acceptance that hydropower can significantly contribute to sustainable outcomes, provide access to energy, assist the poor, mitigate greenhouse emissions, reduce air pollutants, mitigate flooding and reach areas that grid systems cannot traditionally reach. It is essential that any potential hydropower development considers environmental outcomes, in addition to economic and social, from inception. Succinct introduction to the major considerations for small hydropower development that can enable rapid assessment of potential environmental considerations is lacking in the Lower Mekong Basin. It is



important that potential impacts are understood well before the detailed design phase and after construction is finalised. This particular document has a strong focus on hydropower issues relating to fish and specifically aims to provide guidance for:

1. Policy development
2. Government decision making
3. Helping developers to understand requirements
4. Ensuring environmental considerations are addressed

Most countries have active guidelines for hydropower which consider triple bottom line outcomes. The hydropower industry largely recognises inter-relationships between these three beneficiaries but it is important that all are considered equally at an early stage. Addressing these concerns early in the process can avoid much greater costs mitigating these issues in the future. A core, and fundamental principle to be applied is the precautionary approach. IHA (International Hydropower Association) guidelines state that the precautionary principle should be guided by:

- Evaluation to avoid serious or irreversible damage to the environment
- Consideration of the need for electricity and a reliable water supply to alleviate poverty and enhance living standards
- An assessment of risks associated with various options

Accepting application of the precautionary principle allows for development to proceed in the absence of all required data to mitigate a risk. Developers should take stock of all available information at any given time to ensure that environmental obligations are being met. Within this report, the considerations specific to small hydro development are presented and discussed in the context of approval processes relevant to all countries within the Mekong River basin.

## 1. General Introduction

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### 1.1 Mekong River ecology

Fish in tropical floodplain rivers are adapted to large seasonal hydrological changes between wet and dry seasons. Reproduction and growth are optimized during the wet season inundation whilst localized processes in refuge habitat dominate during the dry season (Faggotter, *et al.* 2013). Floodplain habitat is inundated during the wet season and can either dry completely or to a series of refuge pools during the dry season (Junk, *et al.* 1989). During the wet season, floodplains are important sources of spawning, nursery, and feeding habitat for both adult and juvenile fish (Winemiller and Jepsen 1998). High connectivity of habitats, which allow for the free movement of fish within and between main-stem and floodplain habitats, is therefore critical for productive fish communities in tropical rivers (Lundberg, *et al.* 2000).

The Mekong River is the largest river in southeast Asia and the 12th longest river in the world (Baran and Myschowoda 2008). It has an estimated length of 4,350 km, drains an area of 795,000 km<sup>2</sup>, and discharges 457 km<sup>3</sup> of water annually. The system is home to an extremely diverse fish community (estimated at over 1,200 species) including megafauna such as the Giant Mekong catfish (*Pangasianodon gigas*) and Giant freshwater stingray (*Himantura chaophraya*) (Coates 2001). It is also home to the critically endangered Irrawaddy dolphin (*Orcaella brevirostris*; (Mounsouphom 1994). The system has a high degree of species endemism dominated by main-channel specialist (white), floodplain specialist (black), and more generalized channel and floodplain (grey) species (Jensen 1996). Fish have a strong economic and social value in the Lower Mekong River Basin (located in Lao PDR, Thailand, Vietnam, and Cambodia; (Garrison, *et al.* 2006), with the Mekong River capture fishery accounting for 2% of the total annual global harvest and involving more than 80% of households (Hortle 2007). The fishery has a value at first sale between \$US 2000 and 4000 million. Besides economic importance, fish are also an important source of protein and calcium for people; accounting for 48% (Lao PDR) and 79% (Cambodia) of total animal protein consumption (Hortle 2007).

### 1.2 Development in the Lower Mekong River Basin

The Mekong is a typical tropical floodplain river; with high floodplain inundating rains during the wet season and low base flows during the dry season. Mekong floodplain soils are extremely fertile and ideal for agriculture (Baumgartner, *et al.* 2012b). But because of peak seasonal flooding events, regulators are required to protect irrigated and rain-fed crops from excessive inundation while also retaining irrigation water in wetlands during the dry season (van Liere 1980). Larger main-stem regulators, fixed-crest dams, and other engineering structures (0 – 12 m high) are also common throughout the Lower Mekong River Basin (Le, *et al.* 2007) and are similarly operated to provide flood protection and regulate irrigation flows (Fox and Ledgerwood 1999). These types of infrastructure block the movement of nutrients and aquatic organisms within and between main-stem and floodplain habitats, thus compromising the ecology of the river system (Thoms 2003).

Research has demonstrated that different designs of irrigation regulators can affect migrating fish (Baumgartner, *et al.* 2006; Marttin and De Graaf 2002). Studies from Australia (Baumgartner, *et al.* 2006) and Bangladesh (Marttin and De Graaf 2002) demonstrate that sluice gates (particularly “undershot” designs that release water beneath the gate (Baumgartner, *et al.* 2006) cause high mortality of downstream-migrating larvae and juvenile fish, but that other designs, such as those that spill water over a fixed crest, have the potential for substantially greater fish survival rates (Baumgartner, *et al.* 2006). As hydropower, flood control, and irrigation networks in the Lower Mekong River Basin expand, or are re-designed to meet the needs of a growing population and agricultural sector, it is essential to understand the physical processes that are affecting fish survival. Identifying and then incorporating more “fish-friendly” criteria into the design phase of new structures is preferable, because retrofitting mitigation measures after initial construction can be costly.

Potentially one of the greatest threats to fish fauna in the Mekong region is the rapid expansion of hydropower development on major streams (Dugan, *et al.* 2010). About 20% of the world's electricity is generated by hydropower (Demirbaş 2006) and it is becoming the fastest growing renewable energy source. The total estimated hydropower potential of the lower Mekong River basin is 30 GW, including both large and small installations (Commission 2010). Currently, 14 main-stem dams are planned for the Mekong River alone and hundreds of smaller units are planned for tributary streams and floodplain wetlands. Hydropower developments have economic and livelihood benefits (Jacobs 1994) but also potentially damaging social and environmental impacts (Dugan, *et al.* 2010). The construction of hydropower dams substantially alters the hydrology and ecology of river systems (Bednarek 2001) thereby altering downstream river flows and water quality (Kite 2001). The disruption of critical upstream and downstream fish migrations is also recognized as a major ecological impact of hydropower developments (Williams 2008).

The significant impact of hydropower and irrigation development on fisheries has been observed in the Columbia River, USA. (Kareiva, *et al.* 2000) In that region, more than US\$7 billion has been spent on efforts to save iconic salmonid species (Williams 2008) by constructing fishways, enhancing fish stocks, screening irrigation diversions, rehabilitating habitat, and providing downstream passage. While this has helped save salmonids from extinction, there is a reliance on hatchery production throughout the entire catchment which remains a significant contributor to salmonid persistence (Williams 2008). Real-world examples, such as this from the Columbia River, demonstrate the potential for major damage to fisheries in the Lower Mekong River Basin (Dugan, *et al.* 2010) and the costs involved in post-construction rehabilitation. In addition to concerns surrounding large-scale hydropower dams, few data are available to assess the potential risk associated with retrofitting existing irrigation networks with small-scale or mini-hydropower facilities.

### **1.3. Developing “fish-friendly” design criteria for river infrastructure**

There is great potential for eco-hydraulic research to support more sustainable development of river infrastructure in the Lower Mekong River Basin. Internationally, advances across a broad range of in-field technologies, such as the balloon-tag recapture technique (Heisey, *et al.* 1996), biotelemetry (McMichael, *et al.* 2010) and sensor fish (Deng, *et al.* 2010) have provided a greater understanding of the hydraulic conditions experienced by migrating fish at different river infrastructure. Three main mechanical stressors associated with infrastructure passage are known to influence fish welfare which include exposure to fluid shear and turbulence, physical strike, and rapid decompression (Odeh and Sommers 2000). The relative importance of these mechanical stressors varies among fish species and it is clear that current mitigation options, developed largely for salmon smolts, are

unlikely to be readily transferrable for the protection of other freshwater species which have different physiological tolerances (Mallen-Cooper 1989;Mallen-Cooper 1999). For fish found in the Mekong River, design criteria need to be developed for a diverse range of species with differing physiological, anatomical, and life-history characteristics.

Hydropower generation generally requires the rotation of a turbine, powered by a blade propeller system. Fish entrained into turbines may experience blade strike injuries (Larinier 2008) which can often be fatal (Deng, *et al.* 2007b). The likelihood for fish to experience blade strikes is dependent on several factors, including water velocity moving through the blades, blade rotation speed, blade spacing, and fish length. By considering these variables, mathematical modelling can be used to predict the probability of blade strikes (Deng, *et al.* 2007b). A technique known as bio-indexing has proven successful in identifying operational ranges that can minimize blade strikes and maximize fish survival (Deng, *et al.* 2007b).

The tolerances of fish to hydraulic stressors like fluid shear and pressure change are typically established under controlled laboratory conditions (Brown, *et al.* 2012b). Laboratory studies allow variables to be isolated in a way that is not possible in field studies. For instance, a fish passing through a turbine or under a sluice gate may experience shear stress, physical strike, and rapid decompression all during a single downstream passage, making it impossible to determine which stressor is responsible for injury. By isolating a single form of stressor, researchers can have significantly more confidence in the cause of injury and can assess responses over a large range of exposure levels. Field studies still have an important role to play to validate laboratory-generated models and to verify fish passage outcomes post-construction for new or improved infrastructure technologies.

Fluid shear stress describes the interaction that occurs between two masses of water moving in different directions (Cada, *et al.* 2007). Any fish trapped in the boundary between the two intersecting water bodies would be involuntarily torn in opposing directions (known as “shear stress”), which can cause injury or death at elevated levels of shear (Deng, *et al.* 2005). Fish are exposed to various levels of shear on a daily basis (Cada, *et al.* 2007;Deng, *et al.* 2005). Fluid shear can occur in natural riffles, at the base of waterfalls, or in eddies and backwaters. When fish are exposed to unusually high levels of shear, fluid shear becomes a substantial welfare issue. The use of shear flumes, where fish can be exposed to user-defined levels of shear stress created by a high pressure jet, are a useful way of identifying the upper tolerances of fish (Deng, *et al.* 2005).

All fish that pass through a regulator or hydro turbine experience pressure change (Brown, *et al.* 2012b) but the severity is dictated by the route of passage, type of infrastructure, and the operating head. A rapid decompression can expand gas-filled organs in the fish or cause gas in the blood to come out of solution. These conditions lead to barotrauma injuries, which may include rupturing of the swim bladder, internal haemorrhaging, exophthalmia (eye pop), and emphysema of internal organs such as the gills, heart, eyes, and fins (Brown, *et al.* 2012b). Because a large range of pressure changes may be experienced in the field, laboratory studies similarly need to expose fish to a suitably large range of pressure changes. To determine critical tolerances that result in injury and death, laboratory investigations typically involve the use of purpose-built barometric chambers (Stephenson *et al.* 2010, (Brown, *et al.* 2012b). These chambers allow fish to be held for an extended period to acclimate them to a given depth and pressure prior to exposing them to rapid (within a fraction of a second) decompression, thereby simulating passage through a weir or turbine. Unlike chambers typically used to study the barotrauma associated with recreational angling, chambers

used to study the barotrauma associated with infrastructure passage need to generate pressures significantly below those of atmospheric levels and at significantly faster rates (Pflugrath, *et al.* 2012).

## **1.4 Towards sustainable river development in the Lower Mekong River Basin**

The expansion of existing irrigation and hydropower networks is inevitable not only for the Mekong, but for most river systems throughout the world. However, there is an urgent need to ensure that rapid development does not compromise the sustainability of fisheries that provide important social, economic, and ecosystem services during a time of unprecedented population growth and climate change. Significant progress has been made in determining “fish-friendly” design criteria to promote improvements in the downstream passage survival of salmon smolts at dams throughout the Columbia River basin (Brown, *et al.* 2012a; Williams 2008). However, the North American perspective also illustrates how difficult and costly it can be to mitigate fish passage impacts once infrastructure is built.

Therefore, there is an urgent need to better understand the potential risks faced by migrating fish at existing and proposed infrastructures. In some instances, the installation of certain mini-hydropower units on existing irrigation structures may have the potential to provide renewable power to regional areas, while actually improving the downstream passage of fish because they can reduce passage through traditional regulator gates that can cause injury and mortality. If so, widespread application of these units could help to maintain and improve capture fisheries, provide options for cheap sustainable power in rural areas, and assist with the development of regional industry. But until more data are gathered to assess the real risks faced by fish at proposed projects, resources management agencies are likely to take a conservative approach and may refuse construction consent because of the potential for ecological damage (Baumgartner, *et al.* 2012a).

The completion of laboratory trials to determine the susceptibility of Mekong species to shear stress, blade strikes, and pressure change is an essential first step to influencing future infrastructure design. As experiments progress, it will become clearer which species and life stages (e.g., eggs, larvae, juveniles, or adults) will require additional consideration during infrastructure design and operation. Ideally, the tolerances of susceptible fish species (such as fragile drifting fish eggs and larvae) should be used to develop criteria that can inform the engineering design phase. After infrastructure construction, field studies should be conducted to validate any assumptions made during the laboratory and design phases. If required, additional mitigation measures (e.g., screening; although this may not be effective for drifting eggs and larvae that are common in the Lower Mekong River basin) may be warranted, or further improvements can be adaptively incorporated into future construction projects.

At present, development projects throughout the Lower Mekong River Basin are completed for either power generation or irrigation outcomes, and only rarely for multi-purpose projects. Incorporation of biological criteria into these projects can also mean that positive outcomes are generated for fish. Given the cultural, social, and economic importance of fish among river communities of the Lower Mekong River Basin, facilitating sustainable river infrastructure is an essential step for maintaining food security while also improving livelihoods of people in the Lower Mekong Basin.

## 2. Susceptibility of Mekong species to injury and mortality arising from shear stress

### 2.1 Introduction

Hydropower construction and operation can have negative impacts on fish (Dugan, *et al.* 2010). Most fish that approach a hydropower dam can pass via the spillway, the turbine or, if present, via a specially-designed fish bypass facility (Heisey, *et al.* 1996; Muir, *et al.* 2001). Dams that do not possess or require a spillway or bypass facility may be fitted with appropriate exclusion screens to prevent fish entrainment (Muir, *et al.* 2001). However, even well designed exclusion systems only protect a portion of downstream migrants; and often the only route downstream is via the turbine (Cada 1990).

Fluid shear arises when two bodies of water, travelling at different velocities, intersect (Cada, *et al.* 2007). Fish entrained at the interface of these two water masses will experience shear stress but the magnitude is dependent on waterbody mass and velocity and entrained fish body size (Čada, *et al.* 2006). High shear occurs where rapidly flowing water passes near fish passage structures, including spillways, across screens and within turbine draft tubes. Shear stress can have harmful effects on fish but can be influenced through improved turbine design or modified operational practices (Čada, *et al.* 2006).

Biological information has informed the construction of fish friendly turbines; such as the minimum gap runner design that has been applied in the Columbia River (Cada 1990; Deng, *et al.* 2010). These designs contain incorporate attributes that aim to facilitate passage of aquatic biota and are mostly useful for application at new installations or when replacing existing facilities. An important factor in the development of fish-friendly turbines is that the majority of data supporting these improved designs are based on welfare studies of North American salmonoid species. The application of Salmonid criteria to Mekong basin upstream fish passage facilities has failed in many instances; particularly at sites where non-salmonid fish dominate the migratory community (Čada 2001; Mallen-Cooper and Brand 2007). The Lower Mekong Basin has many species which are physiologically and ecologically different from salmonids (Ferguson, *et al.* 2011). The provision of less-damaging turbines or improved operation of existing sites must therefore be based on biological data which complements expected hydraulic criteria experienced during passage.

Understanding critical tolerances of different fish species, to varying levels of hydraulic stressors, are paramount to mitigating harmful effects on other aquatic biota (Odeh 1999). Principles of adaptive management are now actively applied to reduce uncertainty in decision making by applying information learnt through monitoring (Adamson 2008). Although much is now understood about the impact of turbine passage on fish populations, there is little evidence that new information is being applied to improve turbine design and operation in the Lower Mekong Basin. All fish are regularly exposed to varying levels of shear stress. For any given species, however, there must be a critical point where exposure exceeds safe levels to the point where individual fish welfare is affected.

The primary aim of this study was to determine the critical tolerances of some Mekong species to injury and mortality from shear stress. The secondary aim was to provide practical information that could be applied to the design and operation of new hydropower facilities.

## 2.2. Methods

### 2.2.1. Flume construction

A transparent cylindrical plexiglass flume (1.95 m long and 0.44 m diameter) was used to determine critical tolerances of fish to different shear stress rates. A closed circular system was used and water was circulated using an electric pump (Grundfos NBG 125, 3-phase, Max discharge 153 m<sup>3</sup> h<sup>-1</sup>). The flume was connected at one end to a fibreglass reservoir tank (2.10 m long x 2.10 m wide x 0.9 m) (Figure 2.1). The remaining circuit was completed using a 15 cm diameter PVC pipe. On entry to the cylindrical flume, a conical plastic nozzle was installed to reduce the diameter flow from 15 cm to 5 cm (Figure 2.2). The restriction caused by this reduction created a high velocity submerged jet when the pump was operated. The approach generates a quantifiable shear environment where water from the flume becomes entrained in the jet stream (Neitzel, *et al.* 2000). Given the nozzle diameter and pump capacity, maximum velocities of 18.3 m s<sup>-1</sup> could be achieved. A rotating shut off valve was installed within the circulating line to reduce the pump output and enable manipulation of the shear environment at the nozzle (Figure 2.1). A clear polycarbonate tube was fixed above the submerged jet at an angle of 30° was used to introduce fish within 30mm of the submerged jet (Figure 2.2).

### 2.2.2. Characterisation of shear environment

Flow and shear strain levels were calculated on the basis of those used in previous studies (Neitzel, *et al.* 2004). A flow meter (Wollman Silver Turbo Water Meter, ARAD Waterworks®) was fitted to the circulating pipe to calculate overall pump discharge. Velocity measurements were taken at the point where fish were released. Flow velocities (ms<sup>-1</sup>) were calculated by converting the velocity head (m) measured with the pitot tube and using Bernuolli's equation:

$$H = \frac{v^2}{2g}$$

Where  $H$  is the total head (m),  $v$  is the velocity (m s<sup>-1</sup>) and  $g$  the gravitational constant (m<sup>2</sup> s<sup>-1</sup>).

Shear strain ( $\tau$ ) can be described as the changes of water velocity ( $\vec{\mu}$ ) produced over the distance ( $y$ ), and it is expressed as strain rate (cm s<sup>-1</sup>cm<sup>-1</sup>). The exposed shear rate during this study was estimated using the equation:

$$\tau = \frac{\delta\vec{\mu}}{\delta y}$$

Based on possible adjustments of the flow regulating gauge, mean nozzle velocities were 3, 14, 24, 32 and 34 m s<sup>-1</sup> and corresponded with shear strain rates of 18; 446, 880; 1267 and 1296/s .

### 2.2.3. Fish Exposure experiments

Due to delays in construction of shear flumes in Lao PDR, it was decided to proceed with experiments using facilities available in Australia but using species commonly available in the ornamental aquarium trade. A proof-of-concept study was initiated to ensure that the approach and general procedures were sufficient to understand fish tolerances. Experiments were performed on Silver shark (*Balantiocheilos melanopterus*) (Figure 2.3). The species was historically known from the Mekong region but has now become rare or extinct. The species is popular and is readily available from captive breeders.

Fish were housed in a temperature-controlled (24 °C) 2000 L fibreglass aquarium prior to experimentation. Six treatments were assessed. Each of the five calculated shear stress values (18.20, 446.22, 880.80, 1267.02 and 1296.87/s) and a zero shear control. The zero shear control sought to determine if injury or mortality may have occurred due to interactions with the flume or net, irrespective of fish being exposed to the submerged jet. Five replicates of twenty fish were completed for each individual treatment or control providing 30 experiments in total.

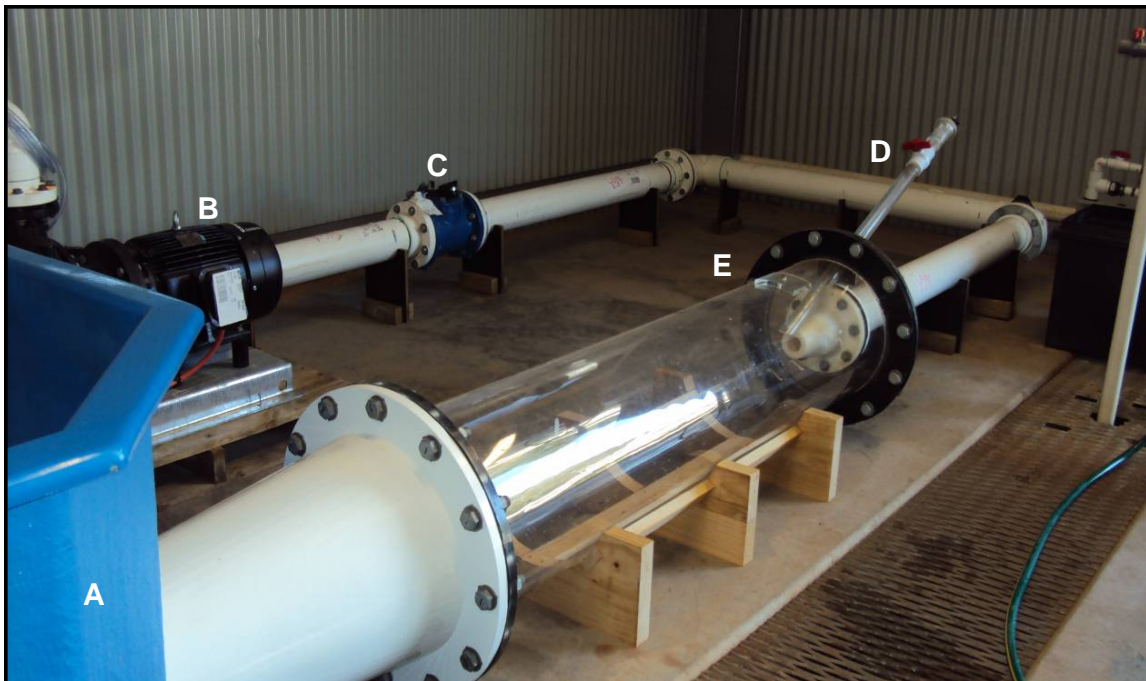
Experiments commenced by placing an individual fish into the transparent delivery tube. For each experiment the five fish were introduced into the shear jet individually and collectively recaptured from the fibreglass reservoir. Fish were then individually weighed, measured for length and then inspected for signs of injury or mortality. The next experiment was then initiated. Upon the completion of experiments, all live fish were placed into a holding tank and observed for 48 hours post experimentation to determine any delayed effects. .

#### **2.2.4. Fish Responses to exposure**

Fish were initially categorised into two groups, 'mortality' or 'injured'. Injured fish were categorised into several different categories including exophthalmia (eye pop), fin damage, scale loss, operculum damage, spinal damage or bleeding.

#### **2.2.5. Data Analysis**

Logistic regression used to analyse the effect of different shear strain on injury or mortality. Injury and mortality were modelled separately but there were only two possible outcomes from the experiment. Two difference response variables were investigated (1) the proportion of mortality and (2) the proportion of injury. Shear stress was applied as the independent variable. Outcomes of each experiment (including the five treatments and one control) were included in the analysis.



**Figure 2.1. Photo of the shear flume demonstrating the reservoir (A), the Grundfos pump (B), in-line flow meter (C), the fish delivery tube (D) and the transparent cylindrical tube (E). (From Boys et al in prep).**



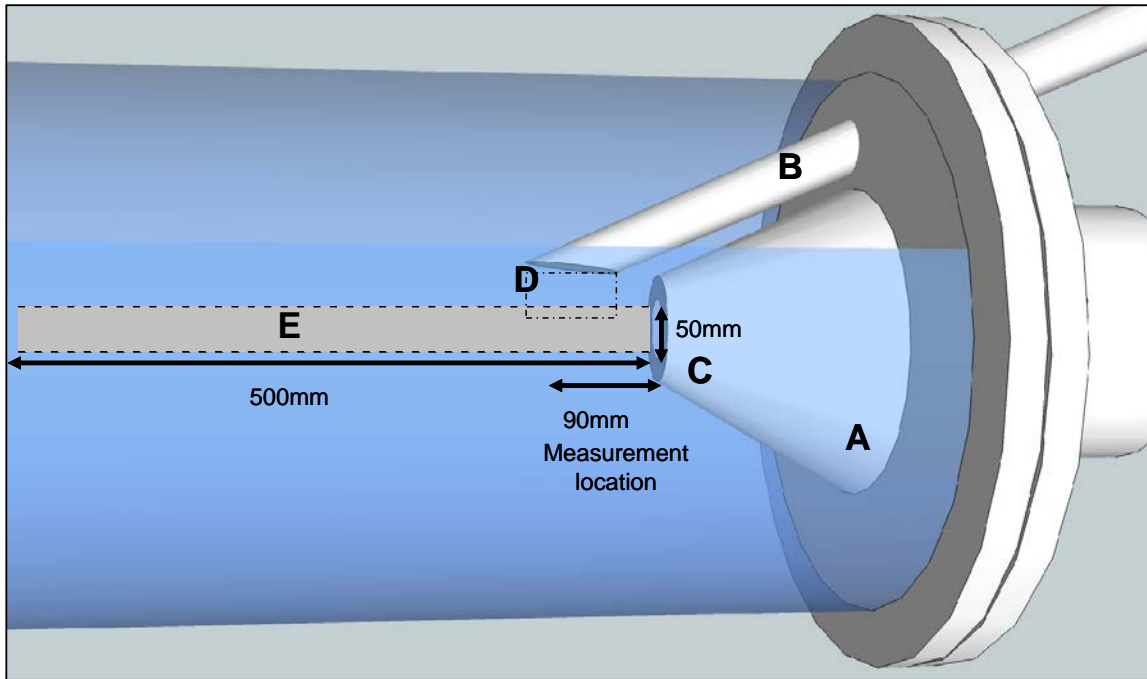


Figure 2.2. Plan view of the jet in the test facility that shows the Nozzle (A), the deployment tube (B), the edge of the jet (C), the fish exposure point (D) and location of the flow establishment zone (E). (From Boys *et al* in prep)



Figure 2.3. Silver shark (sometimes referred to as Bala shark; *Balantiocheilos melanopterus*) which was used as a test species in these pilot experiments (Photo courtesy of Fishbase.org).

## 2.3 Results

A total of 120 fish were used of which 12 died and 83 experienced injuries. No fish died in control, 18/s or 446/s shear strain groups (Table 2.1). Most mortality (n = 10 fish) occurred in the highest shear strain group. Logistic regression predicted no mortality at shear stress levels less than 600/s (Figure 2.4). An estimated 55.2% mortality was predicted to occur at the highest modelled shear level (1296/s) (Figure 2.4; Figure 2.6).

Injuries occurred in each treatment group, including the no shear control. All injuries in the no shear control were associated with scale loss. Logistic regression predicted 42% injury likelihood under control conditions which increased to 91% under the highest shear assessed (Figure 2.5). In the 18s and 444/s groups fin damage and bleeding also became apparent. Operculum injuries began to appear in the 880/s group. In the 1204/s group some fish began to experience exophthalmia, whilst at the highest shear, spinal injuries also occurred.

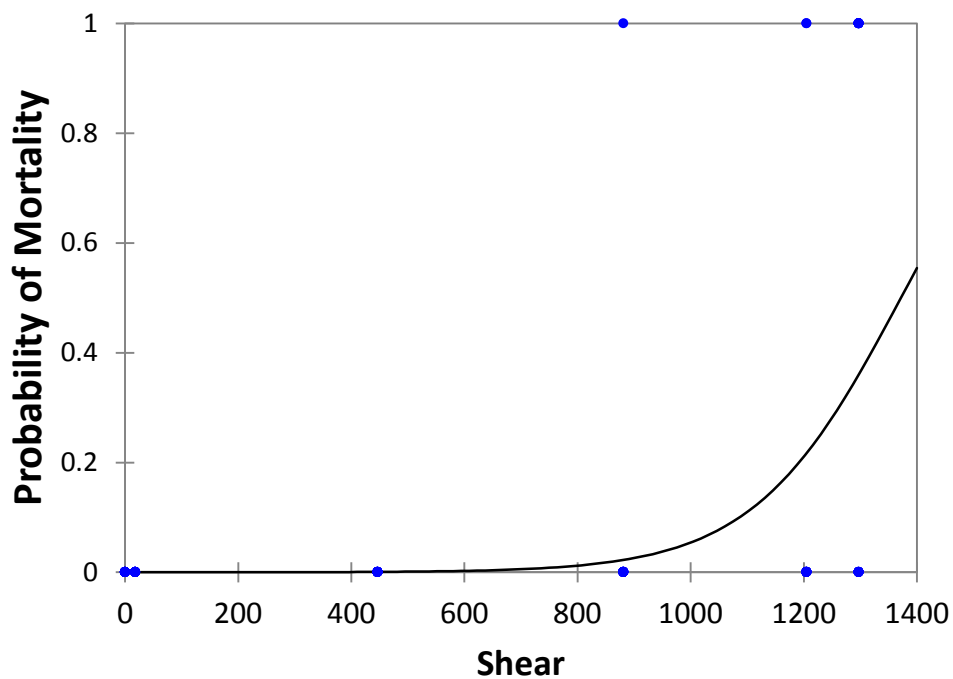


Figure 2.4. Probability of mortality arising from exposure to different levels of fluid shear.

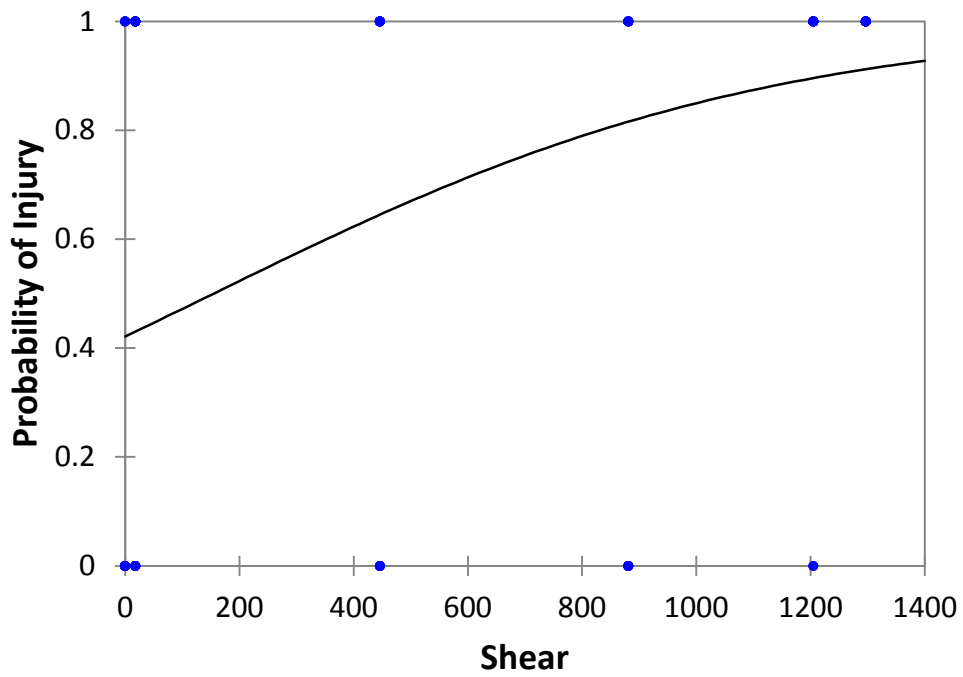


Figure 2.5. Probability of non-fatal injury arising from exposure to different levels of fluid shear.

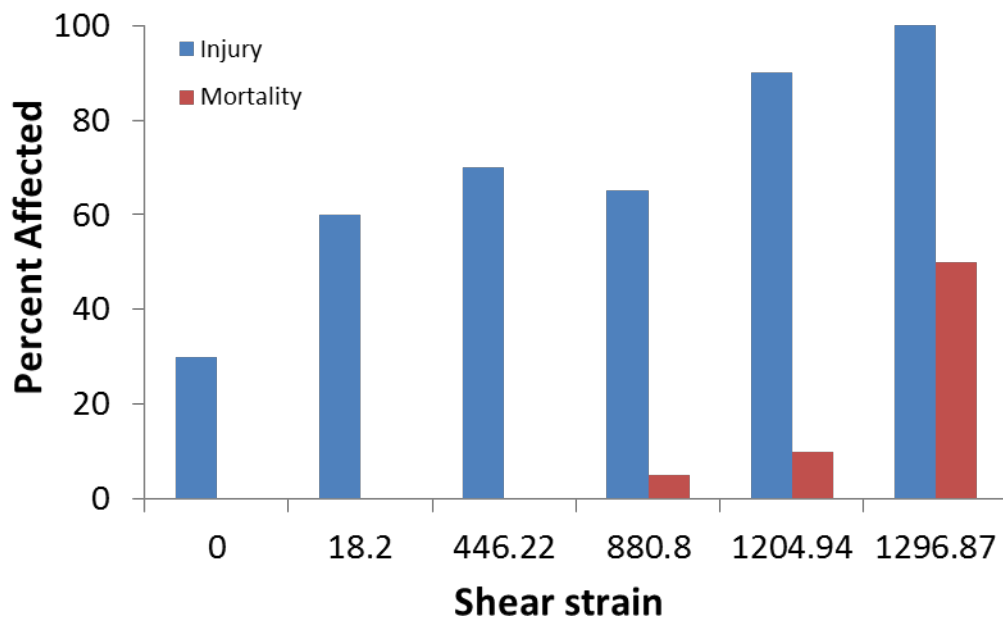


Figure 2.6. Percent of fish that experienced injury or mortality for each level of shear stress exposure. Bars show total percentage of affected fish pooled within each treatment.

**Table 2.1. Summary statistics for pilot shear strain experiments conducted on silver shark. Length (FL) gives the mean length and standard deviation of fish within the treatment, weight gives the mean weight and standard deviation, total died is the total number of fish that died, % died is the percentage of the sample that died, total injured is the total number of fish that were injured, % injured is the total displayed as a percentage.**

Strain rate	Length (mm)	Weight (g)	Total Died	% Died	Total Injured	% Injured
0	64±3	5.09±0.47	0	0	6	30
18.2	64±2	4.68±0.44	0	0	12	60
446.22	66±2	5.03±0.57	0	0	14	70
880.8	65±5	5.10±0.72	1	5	13	65
1204.94	66±3	5.14±0.45	2	10	18	90
1296.87	66±5	4.99±0.61	10	50	20	100

## 2.4. Discussion

The pilot experiments successfully demonstrated that critical levels of fluid shear can be replicated under laboratory conditions. Silver shark were exposed to a range of shear stress levels which led to mortality and critical levels of injury. Mortality only occurred when shear exceeded 600/s. These results suggest, in the first instance, that shear stress below these levels are ultimately required to minimise welfare issues for Silver Shark. Injury severity increased with increasing shear exposure and ranged from minor fin and scale shedding at low shear to spinal damage, opercula damage and bleeding as critical thresholds for injury were exceeded.

Laboratory studies have several assumptions which underpin the transferability of data to the field. Firstly, that a flume environment is an accurate representation of hydraulic stress experienced within an active hydro unit. The main reason that laboratory trials are performed is to examine the effects of shear in absence of all other stressors. In a real-world environment fish may be subject to repeat shear exposure and also interactions with other variables such as blade strike or decompression. Previous field studies on fish welfare during downstream passage have found it difficult to identify sources or injury or mortality when all factors interact. For instance, a study on larval survival when passing through sluice gates was able to quantify mortality, but not the factor causing it (shear, physical strike or pressure change)(Baumgartner, *et al.* 2006). Reductionist studies are therefore useful to help understand the contribution of individual factors to fish welfare but do not eliminate the overall need to field validation at a later date.

Secondly, to widely apply these data to improved hydro plant design, it assumes results can be readily applied to other species. Other studies attempting to generalise fish passage solutions using results from other species have had limited, if any success (Mallen-Cooper and Brand 2007). The preferred approach for Mekong species would be to identify a range of high priority species and focus on developing a set of specific design and operation criteria. In addition, fish are most likely to experience shear stress when trapped between two separate moving water bodies, thus injury probability will subsequently be proportional to fish size and the mass of the interacting water bodies (Neitzel, *et al.* 2000). Additional information on how larval and adult stages respond to fluid shear is needed to determine the transferability of these data to new installations.

Thirdly, we assumed that the post-experimentation observation period (24 hours) was sufficient to detect any delayed mortality. In effect, the short observation period likely underestimated longer term mortality. Injuries which may have led to disease or infection may not have produced clinical symptoms within 24 hours. Many infections could take many days to reach critical levels and longer

observation periods would be required. Delayed mortality has been previously observed for salmonoid passage in North America (Caudill, *et al.* 2007; Ferguson, *et al.* 2006). At some sites, delayed mortality, which was up to 48 hours post passage, was between 46-70% total mortality during turbine passage in the Columbia River (Ferguson, *et al.* 2006). These observations suggest instantaneous mortality will only provide limited data on passage survival and studies which observe fish for longer periods, post experimentation, should be applied to future studies on Mekong species.

Fluid shear and turbulence are natural phenomena which are important and form part of natural adaptations between fish and their environment (Neitzel, *et al.* 2000). Elevated levels of shear are known to be damaging especially considering that most naturally occurring levels are below 200/cm (Table 2.2) (Neitzel, *et al.* 2000). Lower levels of shear had minimal impacts on silver shark other than scale loss. Higher levels of shear were more damaging and half of the experimental fish died at the highest level tested. Computational modelling suggests that shear stress in hydro turbines is predicted to exceed the highest level tested in this study (Neitzel, *et al.* 2000). However, the distribution of shear throughout a turbine suggests that levels over 1,000 cm/m/cm<sup>2</sup> occurs in less than 10% of the overall draft tube area (McEwen and Scobie 1992).

Even though most areas within a draft tube should be within limits safe for silver shark, only a brief exposure to levels higher than those studied here is enough to cause injury and potential mortality. Using computational fluid dynamic data to determine the overall shear profile within a turbine would be a useful mechanism to determine the potential for injury to silver shark, prior to construction.

The survival of turbine-passed fish depends greatly on the characteristics of the hydropower plants and fish species. For instance, previous studies have determined that fish orientation (whether entering head or tail first) can influence survival probability (Deng, *et al.* 2005). Whilst there are many factors that could influence fish welfare, the ultimate challenge for laboratory studies is to provide results that could be adaptively included in future design parameters. It is impossible to perform research on every species for the full complement of operating scenarios prior to commencing development activities. River development therefore requires a stepwise approach to construction activities.

In the first instance, development decisions should be transparent and based upon the best-available data. For new designs or applications this should be based on the precautionary principle where conservative design criteria are applied until new data suggest different criteria can be considered. The use of computational fluid dynamics can assist in this regard, and provide some scientific confidence regarding expected hydraulic conditions. It is essential however, that any assumptions about biology and fish-friendliness are validated post-construction to facilitate application at other sites. Should fish mortality be observed, causal factors should be identified and learning applied to future construction. Using biology to inform hydrology, in this context, is a direct application of adaptive management to delivery sustainable development outcomes.

**Table 2.2. Published estimates of shear stress in natural and man-made altered environments (reproduced from Neitzel *et al*, 2000).**

Environment	Shear Stress (N/m <sup>2</sup> )	Literature Cited
Water column in a trout stream, average flow	<1.0	Fausche and White (1981)
Small streams, near bed	<1 - 7	Lancaster and Hildrew (1993)
Medium-size streams, near bed (90 measurements)	Most < 30, but some > 200	Statzner and Muller (1989)
Flash floods, small basins	61-2,600	Costa (1987)
Floods, large rivers	6-10	Costa (1987)
Blub turbine draft tube	500 - 5,421	McEwen and Scobie (1992)
Near ship hulls and wakes	7.6 - 40.4	Morgan et al (1976)
Near barge propeller	> 5,000	Killgore et al (1987)

## 2.5. Conclusions

A specifically designed shear flume provided the first data on Mekong species susceptibility to fluid shear. Silver shark were exposed to a range of fluid shear and a critical threshold for mortality was determined to be at levels of 600/s or greater. The overall construction of an experimental shear flume will enable scientists within the Lower Mekong Basin to benchmark the impact of hydraulic forces on Lower Mekong species. By extending the results of this study to other species and size classes, a greater understanding of potential impacts of hydro development will be gained. Considering these results in the context of hydropower design and operation will lead to improved conditions for fish over the long term. It is important that the techniques and preliminary data presented here are extended to developers and engineers so that fish welfare issues can be considered during the design phase of future hydropower projects.

### 3. Susceptibility of two Mekong species to injury and mortality arising from simulated pressure changes

#### 3.1. Introduction

Fish that experience a rapid pressure change may experience barotrauma (Brown, *et al.* 2009). Barotrauma can include swim bladder rupture, emboli, exophthalmia (eye pop) or stomach eversion and arises because fish cannot regulate gases quickly enough to cope with the pressure change. Whether barotrauma represents substantial welfare concern depends on critical thresholds tolerable by fish and the ratio of pressure change (Brown *et al.* 2012). Barotrauma is commonly seen from fish that have passed through a turbine. Barotrauma could also happen when fish are rapidly brought to surface pressure while passing through a spillway with an entrance deep in the water column, commonly referred to as “deep spill” or “traditional spill” vs. “surface spill” (Brown, *et al.* 2009; Brown, *et al.* 2012b).

There are two main pathways for barotrauma which are governed by either Henry’s Law or Boyle’s Law (Brown, *et al.* 2012b). Henry’s Law states that at a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid (such as blood plasma in fish) is proportional to the partial pressure of gas to which it is equilibrated (Loeb 2004). For instance, if an organism is acclimated at surface pressure and then experiences a rapid decrease in pressure such as when passing a hydroturbine, gas may come out of solution and form bubbles in the blood. The situation is analogous to a diver getting the bends (Brown, *et al.* 2012b) where breathing compressed gas leads to supersaturated blood upon returning to surface pressure rapidly. Barotrauma due to Henry’s Law could be a welfare issue for fish that are exposed to pressures below surface pressure. For these fish, passing through areas of low pressure, such as through hydroturbines, could lead to decompression, supersaturated blood and gas bubbles may form in the blood, organs, gills, or fins (emboli). However, Brown *et al.* (2012b) noted that this pathway is not likely to play a major role in barotrauma because the fish are only exposed to very short periods of low pressure when passing a turbine or other water management structure. Thus their blood would only be supersaturated for a fraction of a second.

Boyle’s Law describes how the volume of pre-existing gas increases when pressure decreases at a fixed temperature (Loeb 2004). It is particularly important for fish, most of which have a gas filled structure such as a swim bladder. Fish with swim bladders generally fall into one of two categories, physoclistous or physostomous. Physoclistous fish have a bed of vasculature on their swim bladder known as the rete mirabile (Scholander 1954). The rete is used to regulate swim bladder volume by removing gas from the blood. It is a slow process and can take fish many hours to equilibrate after a small change in depth. Many physostomous fish do not possess a rete and instead have a connection between the swim bladder and the throat called the pneumatic duct (Saunders 1953). If a physostomous fish decreases depth, and the swim bladder volume expands according to Boyle’s Law, and excess gas can be vented through the pneumatic duct. However, since physoclistous fish do not have a pneumatic duct, the swim bladder will expand and may be more likely to rupture when the fish are decompressed than physostomes.

These two physical Laws, and the associated fish physiology, are relevant to turbine passage. Whilst shear stress and physical strike may impact some fish that pass through a turbine, all fish will experience some degree of pressure change (Thorncraft, *et al.* 2013). The magnitude of decompression during turbine passage is dependent upon the turbine runner design, the operation of the turbine, the submergence of the turbine runner (*i.e.*, elevation of the turbine runner relative

to the downstream water surface elevation), the total project head (difference between upstream and downstream water surface elevations) and the flow path (Brown, *et al.* 2012b). So once critical thresholds for fish are known, application to hydro design and construction will be possible.

Knowledge of critical thresholds can guide research in more than one way. Within the Pacific Northwest of the US, critical threshold pressure criteria are being used to reduce the differential turbine pressures fish are exposed to with an objective to minimize the risk of barotrauma. Turbine designers can use these pressure limits to reduce damage to fish, while also attaining reasonable levels of power generation, turbine efficiency and a broad head range (Brown *et al.* 2012). Critical pressure thresholds can also be used to optimize turbine operations for safe fish passage.

Laboratory studies are a useful way to understand the effects of pressure on fish in isolation from other factors. The most efficient mechanism to perform such studies is to construct purpose built barometric chambers (Stephenson, *et al.* 2010). Scientists generally use technology such as sensorfish or computational fluid dynamics (CFD) modelling to understand the pressure changes experienced by fish at a dam of interest (Deng, *et al.* 2010). The resultant pressure ranges are then applied to the barometric chambers and used to ground truth a series of exposure trials on fish (Deng, *et al.* 2007c). These data are then used to understand fish welfare issues and applied to existing dam operation and the design of new systems. Most work however, has focused on salmonid species and there are relatively few barometric chambers, worldwide, that can be used for fish studies and can change pressures at a fast enough rate to simulate turbine passage. Most units are located in the United States where there is a rather small availability Lower Mekong species that could be tested.

To obtain data on Mekong species that could be used to inform improved hydro design, a series of barometric chambers were designed and constructed in the USA and shipped to Lao PDR. Units were installed at the National University of Laos and a pilot study initiated. Applicability of these approaches to the Lower Mekong was done using two commonly-available hatchery species. Pilot scale research was done to gain a rough idea of the types of barotrauma injuries that may occur in Mekong species and begin to understand the variability in injuries among fish species. Outcomes of the pilot will be used to inform a larger study on the impacts of pressure-related injury for other species in the Mekong Basin.

## **3.2. Methods**

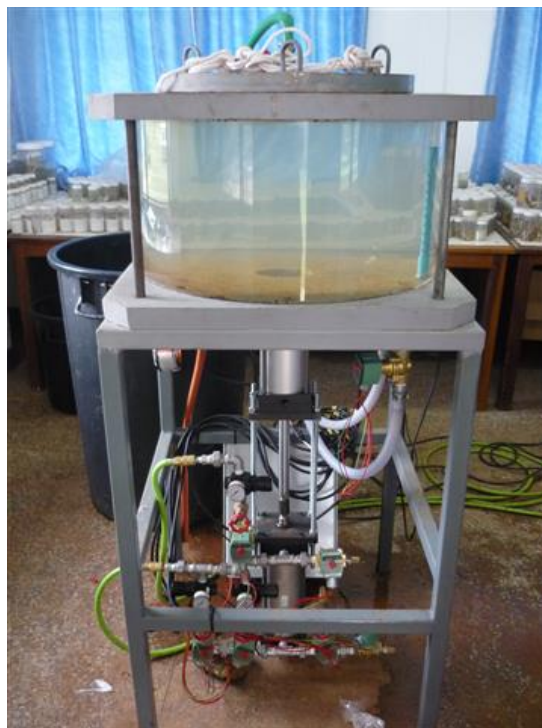
### **3.2.1. Chamber construction**

Two hypo/hyperbaric chambers were used to examine barotrauma in two species of fish to understanding relative the vulnerability to barotrauma during infrastructure passage. The top and bottom plates of the first (large) chamber was constructed out of 25 mm thick steel plate with a 25 mm thick acrylic cylindrical chamber comprising a sealable hatch to introduce and remove fish (Figure 3.1). The second (small) chamber was constructed out of rigid 16mm acrylic with a glass viewing window fitted to permit direct observation of fish during compression and decompression. The chambers were also capable of flow through water (up to  $\sim 50 \text{ L min}^{-1}$ ) while holding fish for long periods of time under pressure. Each chamber was operated via mains electricity contained its own set of valves and pumps to allow independent operation. A pressure sensor was fitted to each chamber to enable instantaneous readings during experimentation.



### 3.2.2 Experimental Treatments

Experiments were conducted at the Dongdok campus at National University of Lao, Vientiane, Lao PDR (Figure 3.2). Experiments sought to determine the effects of relatively rapid decompression on two Mekong species. Experiments were conducted on snakehead (*Channa striata*) (Figure 3.3) and Pa Soi (*Henicorhynchus lineatus*) (Figure 3.4) which were sourced from Nongteng fish hatchery (at approximately 90 days of age). Both fish have physostomous swim bladders (connected to the oesophagus via the pneumatic duct). Previous studies have found that some physostomes are able to expel air via the pneumatic duct during times of decompression and that fish that did expel gas were less likely to have a ruptured swim bladder. Fish with ruptured swim bladders are likely to be unable to moderate their buoyancy which could make them more susceptible to predation and starvation.



**Figure 3.1. Picture of the barotrauma unit showing various electronic valves and system controls. Pressure changes were facilitated by movements of a pneumatically actuated piston situated under the system. The unit was capable of facilitating both increases and decreases in pressure and holding fish under pressure while water flows through, maintaining adequate oxygen supply.**



Figure 3.2. Staff from National University of Laos and Living Aquatic Resources Research centre performing calibration tests on the barotrauma chambers using Lower Mekong species (*Hemibagrus wykoides*).



Figure 3.3. Snakehead, *Channa striata*, a physostomous air breathing fish which was used in the present study (Photo courtesy of Ubolratana Suntornratana, Thai Department of Fisheries).



**Figure 3.4. Pa soi, *Henicorhynchus lineatus*, a physostomous fish which was used in the present study (Photo courtesy of Ubolratana Suntornratana, Thai Department of Fisheries).**

These were initial preliminary experiments which did not necessarily replicate all of the conditions of passing a hydroturbine or other water infrastructure. These experiments should, however, provide a good comparison of the effects of decompression on two fish species. Preliminary data should inform more robust, large scale sampling in the future.

One decompression profile and a control were assessed to simulate the low pressures fish could experience when passing through river infrastructure. Fish were kept at atmospheric pressure (14 psia) for two hours then decompressed to pressures between approximately 1 and 2 psia, then returned to surface pressure. The main aim of this experiment was to gain a preliminary indication about the types of barotrauma injuries that may occur in Mekong species during infrastructure passage including variability in injuries among fish species. A pressure profile of this type would have similarities to passage through a run of river turbine since they can expose fish to relatively low pressures. The experiment also served to determine the ability of pressure sensors to record pressure information in a consistent manner while decompressing. Further efforts will involve adding Sensor Fish to the chambers to ensure that sensors contained in the unit accurately captured the rate of pressure change and extent of pressure change.

An experimental control was performed where fish were introduced into the chamber but pressure was maintained at 14 psia for the two hour experimental period. The treatment sought to determine the effects of handling and transferring fish to the chamber.

### **3.2.3 Fish Exposure experiments**

Both fish species were transported from the hatchery to Dongdok campus via aerated tanks. Upon arrival, fish were transferred to 600 L aerated holding tanks. Fish were fed a daily ration of hatchery crumble but were not fed 24 prior to experimentation. Fish ( $n = 10$  per treatment) were randomly selected from the holding tank and transferred to the barotrauma chambers. After fish were placed in a chamber, it was sealed and a bubble was left at the top of the chamber while the fish acclimated for two hours. A flow was maintained through the chamber during acclimation to ensure a sufficient oxygen supply and constant temperature.

Following acclimation, the bubble of air at the top of the chamber was removed using a bleed valve on the lid. Next, the water flow pump within the chamber was switched off. Valves on the inlet and outlet of the chamber were simultaneously closed. The actions effectively isolated the chamber at the set acclimation pressure prior to decompression. Decompression was achieved by manually activating a linearly actuated piston that withdrew and/or inserted a piston from the chamber to create the desired pressure conditions. Decompression to either 1-2 psia occurred over approximately one second. Fish were then retrieved from the chamber via dip net and inspected for injuries or mortality. Fish were weighed, measured for length and then live fish placed into a recovery tank and monitored for 48 hours post experimentation. The post treatment monitoring period sought to identify any delayed mortality which may have arisen from injuries sustained during the decompression.

Five replicates of ten fish were completed for both the treatment fish and the control fish. No more than ten fish could be used at a single time because each fish contains a swim bladder, which is a gas filled structure. Too much undissolved gas in the chamber can affect the ability of the unit to decompress to low pressures. Ten was deemed the maximum number of fish that could be introduced to the chamber at any time.

#### **3.2.4. Data Analysis**

The overall purpose of these experiments was to perform a short term pilot to determine whether low pressure levels that could be experienced in a turbine could be replicated under laboratory conditions in Lao PDR. Analysis largely focused on quantifying differences in mortality between the two species.

### **3.3 Results**

#### **3.3.1. Decompression experiments**

A total of 100 fish were successfully exposed to decompression and of those, 24 Snakehead died while 3 Pa Soi died (Figure 3.5). All Pa Soi survived control conditions, while 6 control snakehead died. There was some evidence of delayed mortality among both treatment and control fish. Immediate mortality doubled during the post experimental observation period in decompressed snakehead, but not the control (Figure 3.6). While there was no immediate mortality of Po Soi, 3 had died after 48h (Figure 3.7).

#### **3.3.2. Chamber performance**

The chambers were capable of generating rapid decompression from surface to a nadir as low as 1.5 psia. During experiments on snakehead two replicates achieved a nadir of 1.5psia whilst three achieved 1.6 psia (Table 3.1). These equate to ratios of pressure change ranging from 9.1 to 9.7. Pa soi experiments exhibited more variation. Nadir pressures ranged between 1.1 and 1.9 but there was more variation among replicates (Table 3.1). These nadir's generated ratios of pressure change ranging from 7.7 to 15.6 (Table 3.1).

There was some inconsistency in pressure profiles applied to fish during the decompression phase. In one snakehead replicate (Figure 3.8) and one Pa soi replicate (Figure 3.9) fish were compressed temporarily prior to decompression occurring. More replicates demonstrated a pressure profile where fish were rapidly decompressed then brought back to surface pressure instantaneously. Some others were decompressed but then brought back to surface pressure over a matter of seconds. In one Pa soi replicate, fish were decompressed (2.9 psia), inadvertently compressed to 21 psia, then returned to 14 psia.

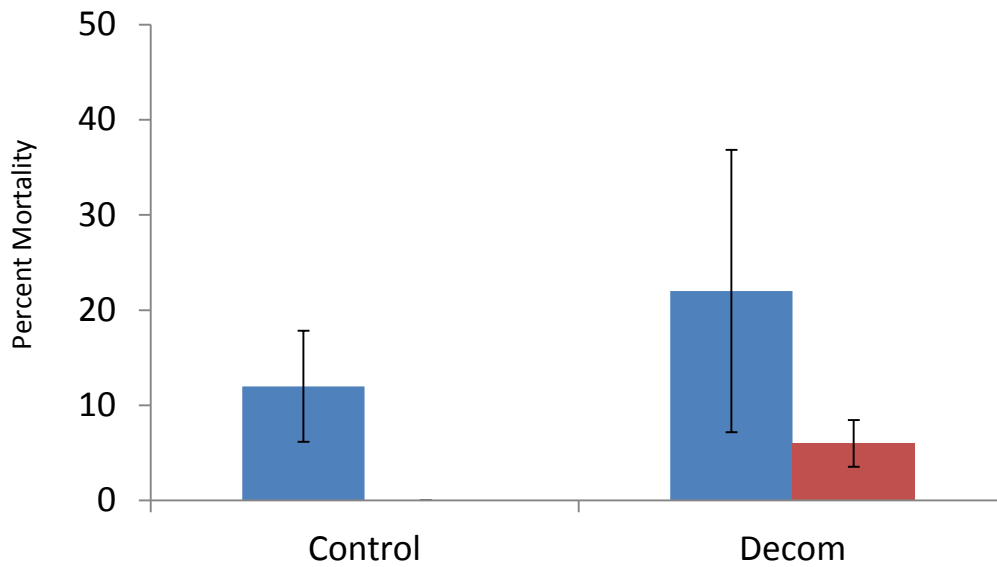


Figure 3.5. Average mortality among treatments for both species used in the pilot trial. Error bars denote one standard error. Red indicates Pa Soi, Blue indicates snakehead.

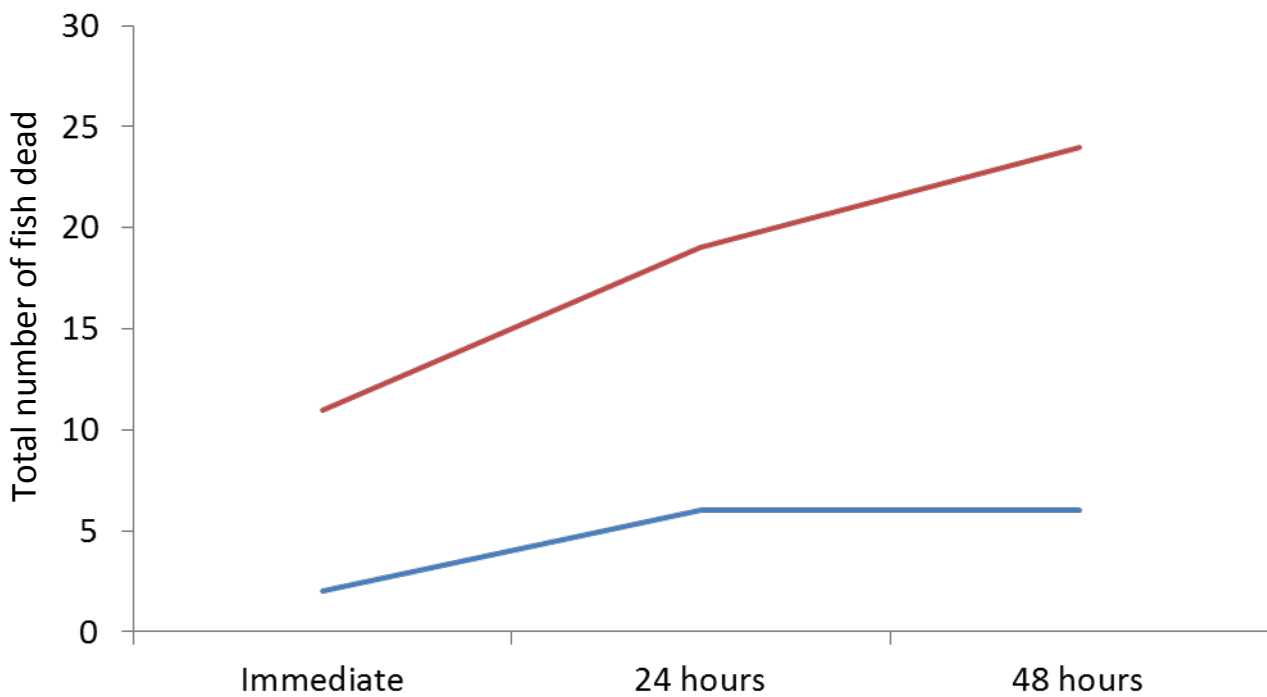


Figure 3.6. Cumulative delayed mortality in snakehead (*Channa striata*) demonstrating cumulative number of fish which died (out of 100) within each post experimentation period. Red is from the decompression treatment, blue indicates the control.

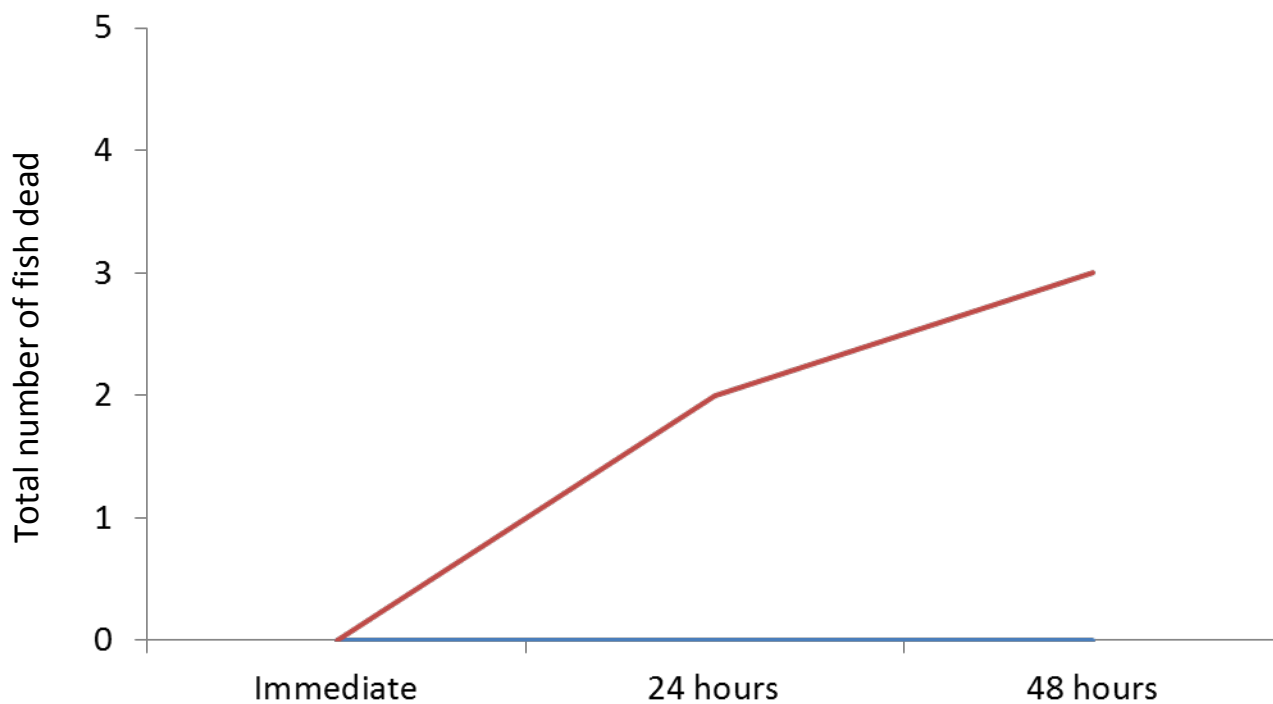


Figure 3.7. Cumulative delayed mortality in Pa Soi (*Henichorhynchus lineatus*) out of 100 fish. These data demonstrate the cumulative number of fish which died within each post experimentation period. Red line denotes decompression treatment, blue line denotes control.

Table 3.1. Ratio of pressure change achieved during rapid decompression experiments for each species.

Replicate (species)	Acclimation Pressure	Nadir pressure	Ratio of change
<i>Snakehead (Channa striata)</i>			
1	14.6	1.5	9.7
2	14.7	1.6	9.1
3	14.6	1.6	9.1
4	14.6	1.6	9.1
5	14.6	1.5	9.7
<i>Pa soi (Henichorhynchus lineatus)</i>			
1	14.9	1.3	11.0
2	14.9	1.3	11.5
3	14.8	1.2	12.3
4	14.2	1.1	15.6
5	14.6	1.9	7.7

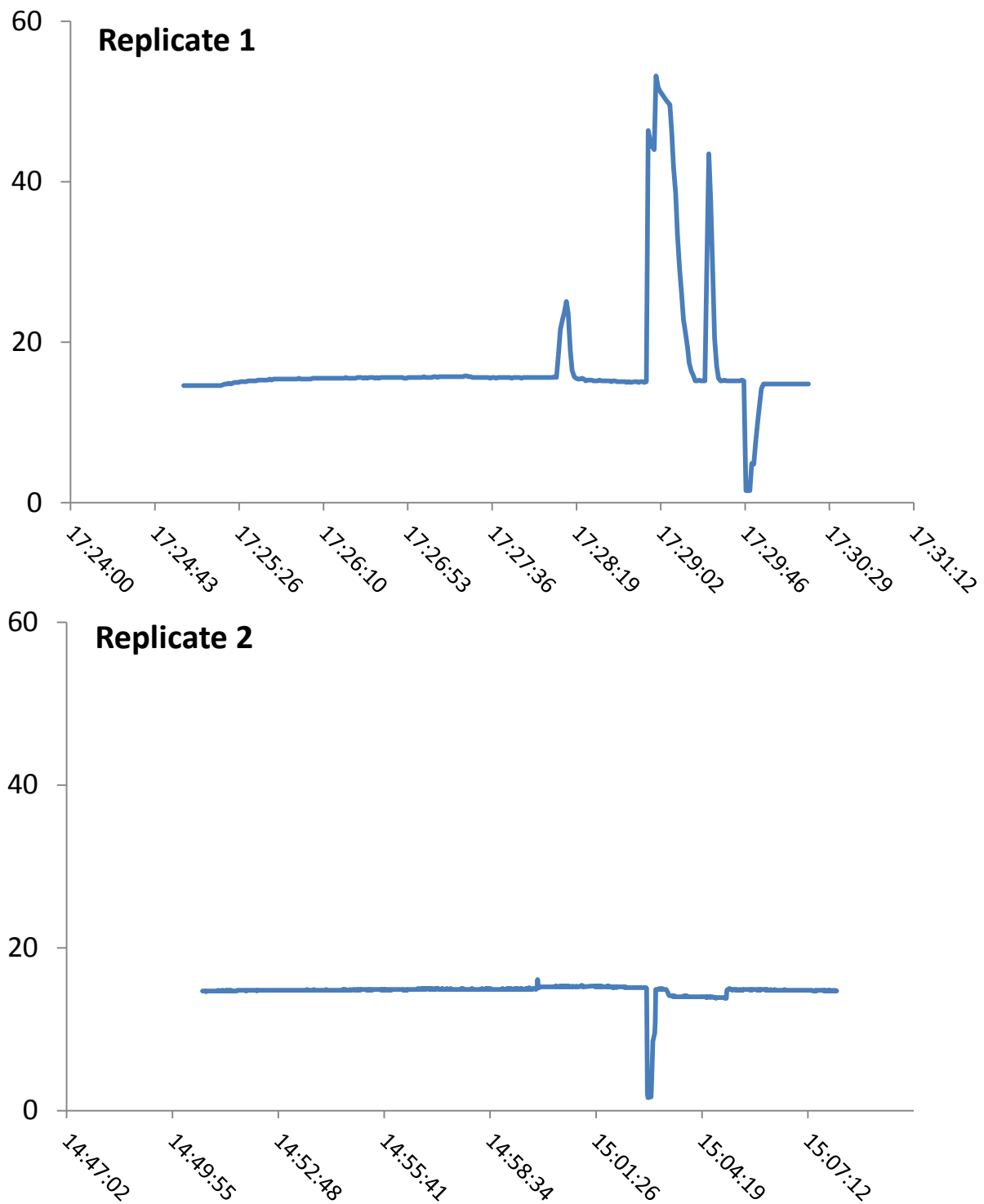


Figure 3.8. Examples of pressure profiles applied during the decompression replicates for snakehead (*Channa striata*).

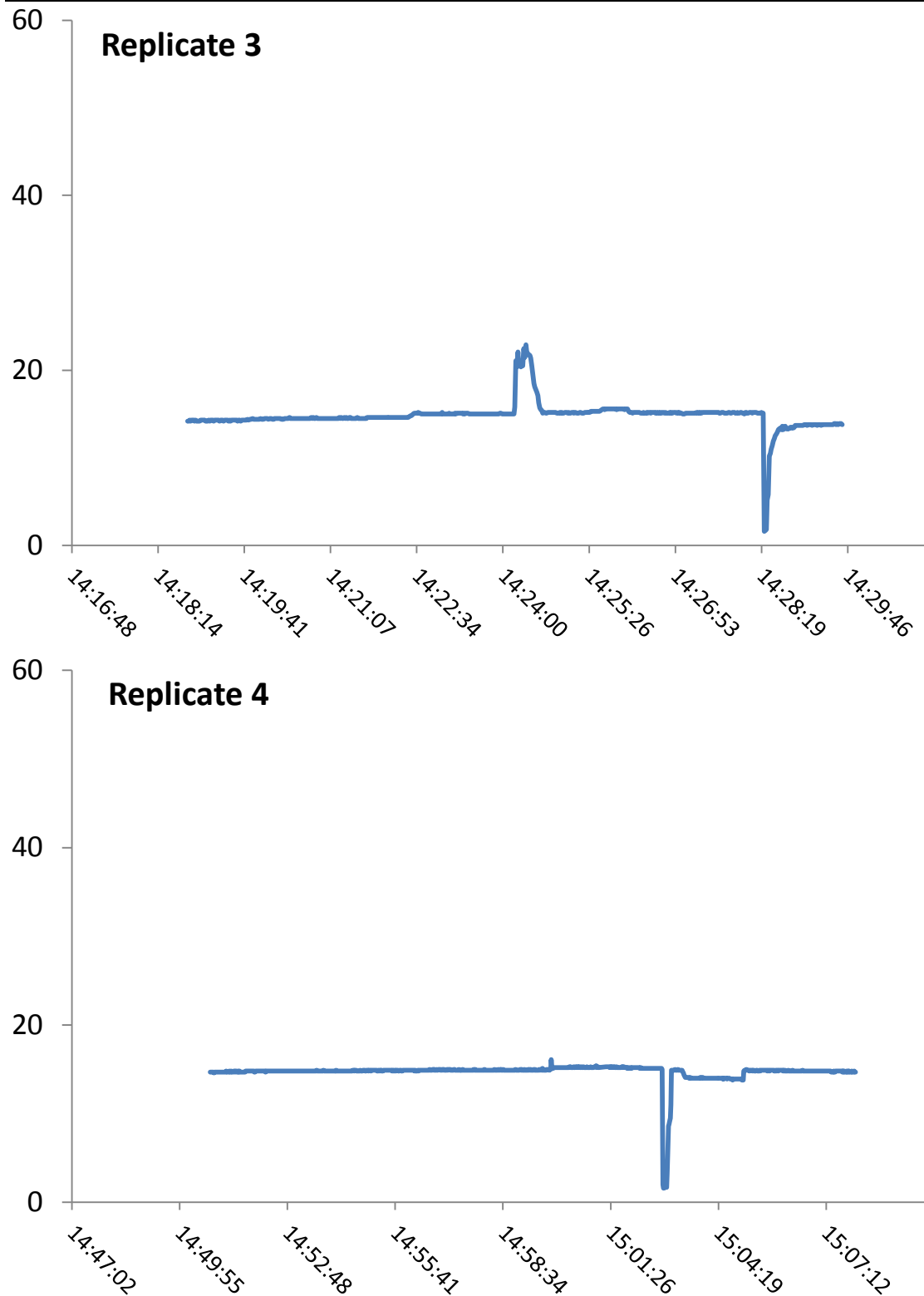


Figure 3.8 (continued). Examples of pressure profiles applied during the decompression replicates for snakehead (*Channa striata*).



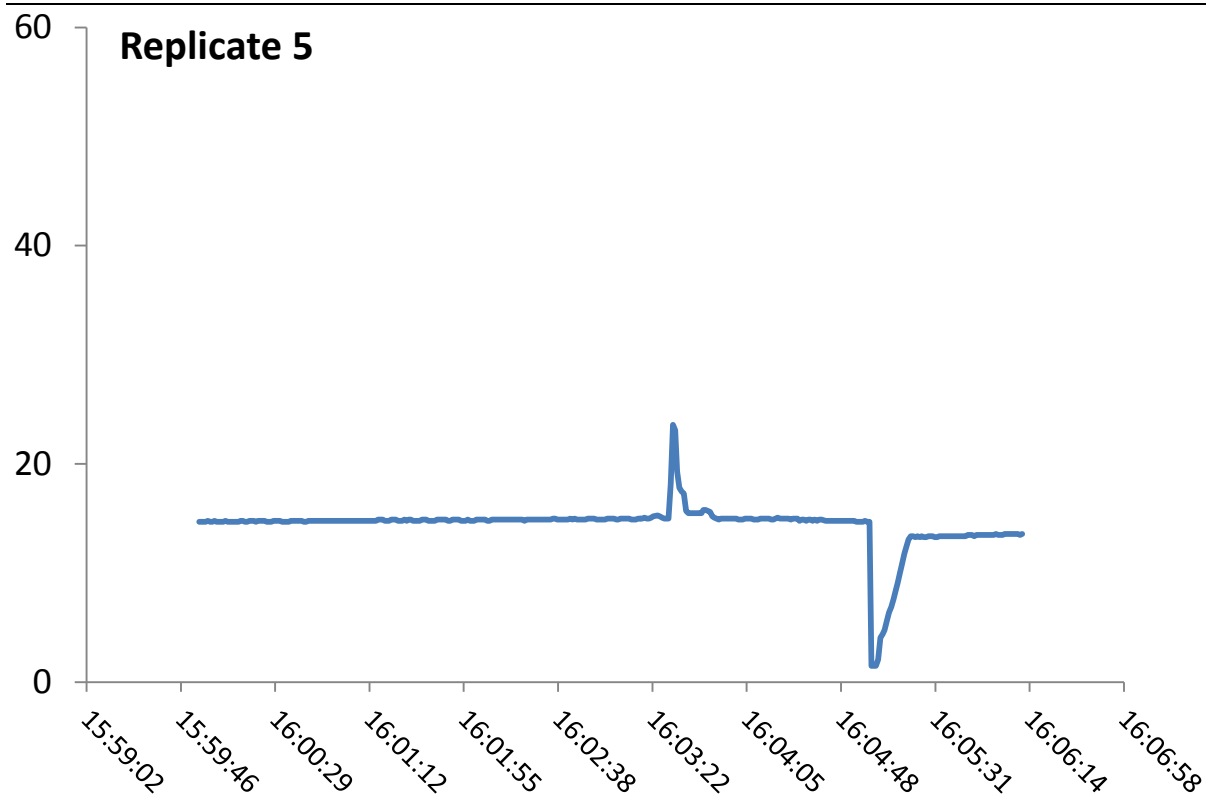


Figure 3.8 (continued). Examples of pressure profiles applied during the decompression replicates for snakehead (*Channa striata*).

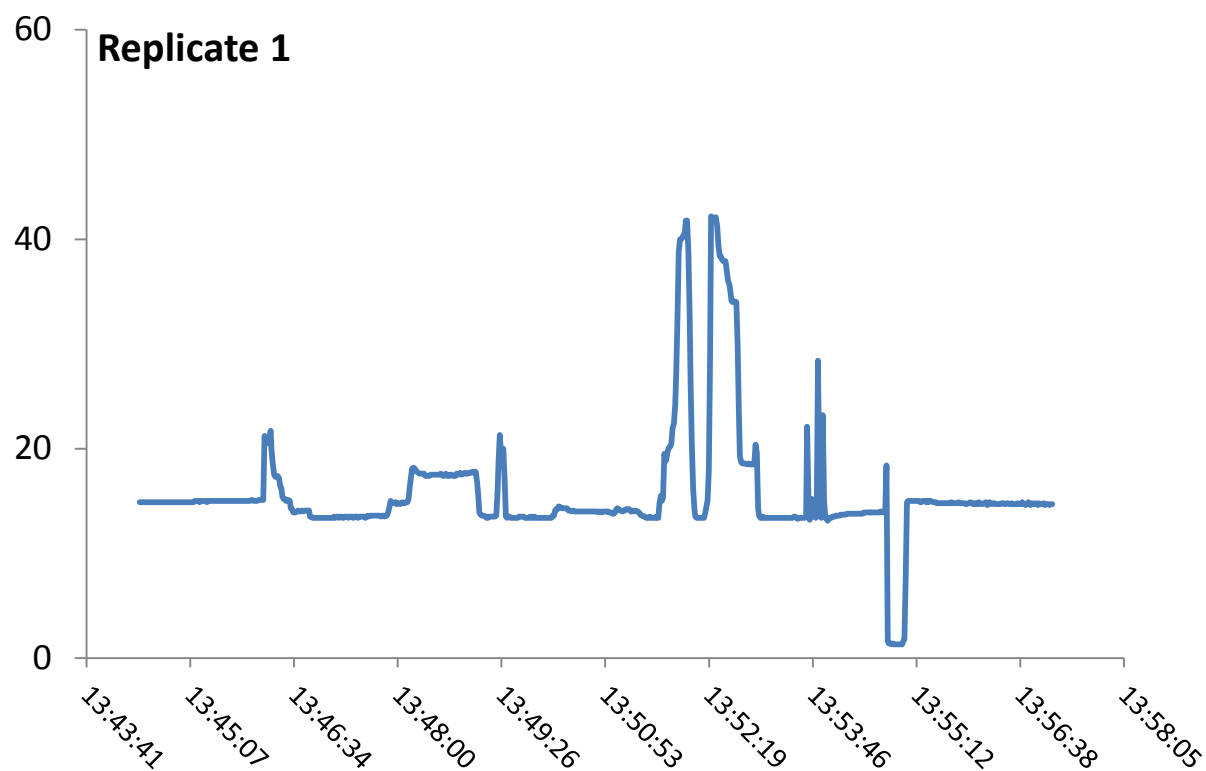


Figure 3.9. Examples of pressure profiles applied during the decompression replicates for Pa soi (*Henichorhynchus lineatus*).

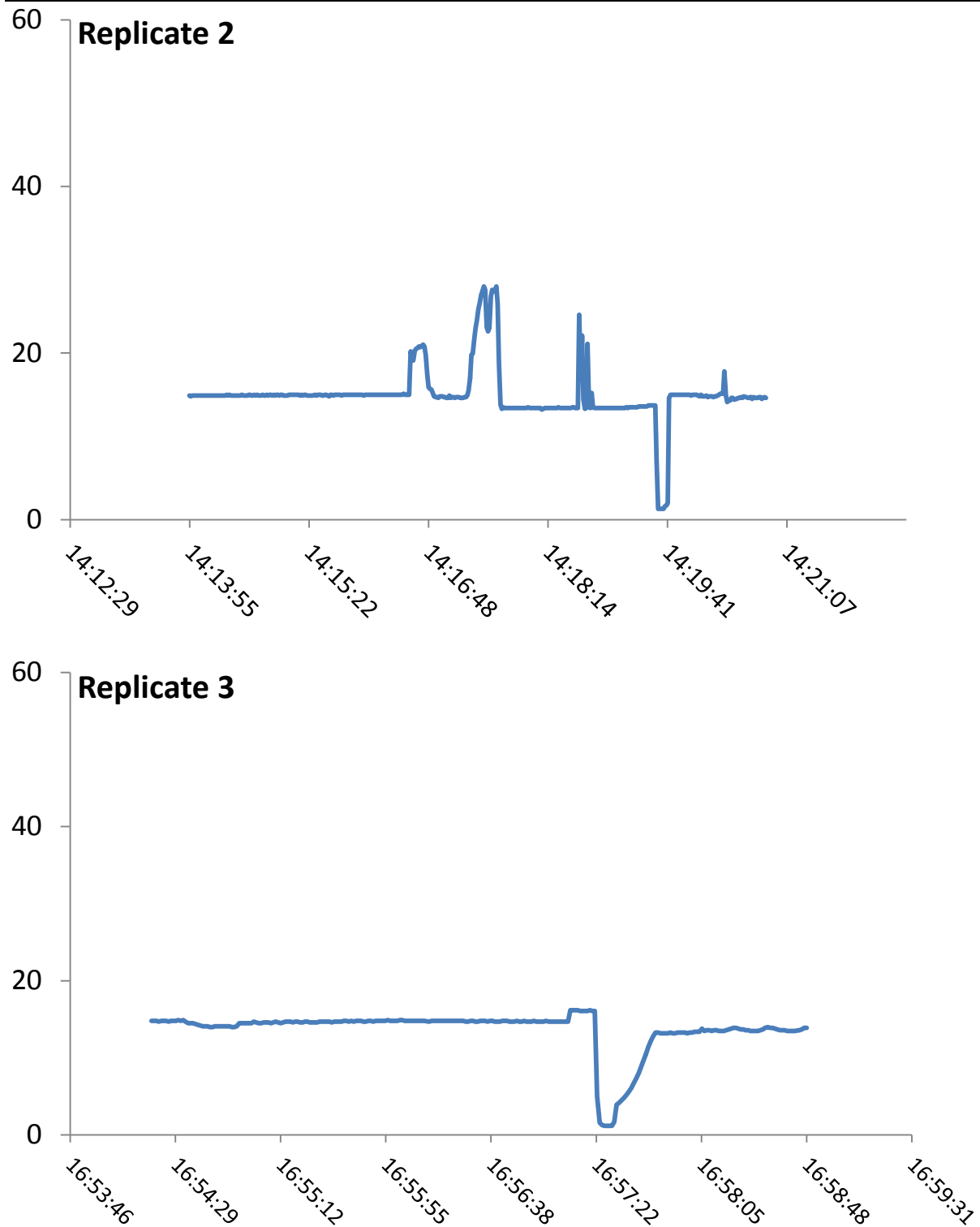


Figure 3.9 (continued). Examples of pressure profiles applied during the decompression replicates for Pa soi (*Henichorhynchus lineatus*).

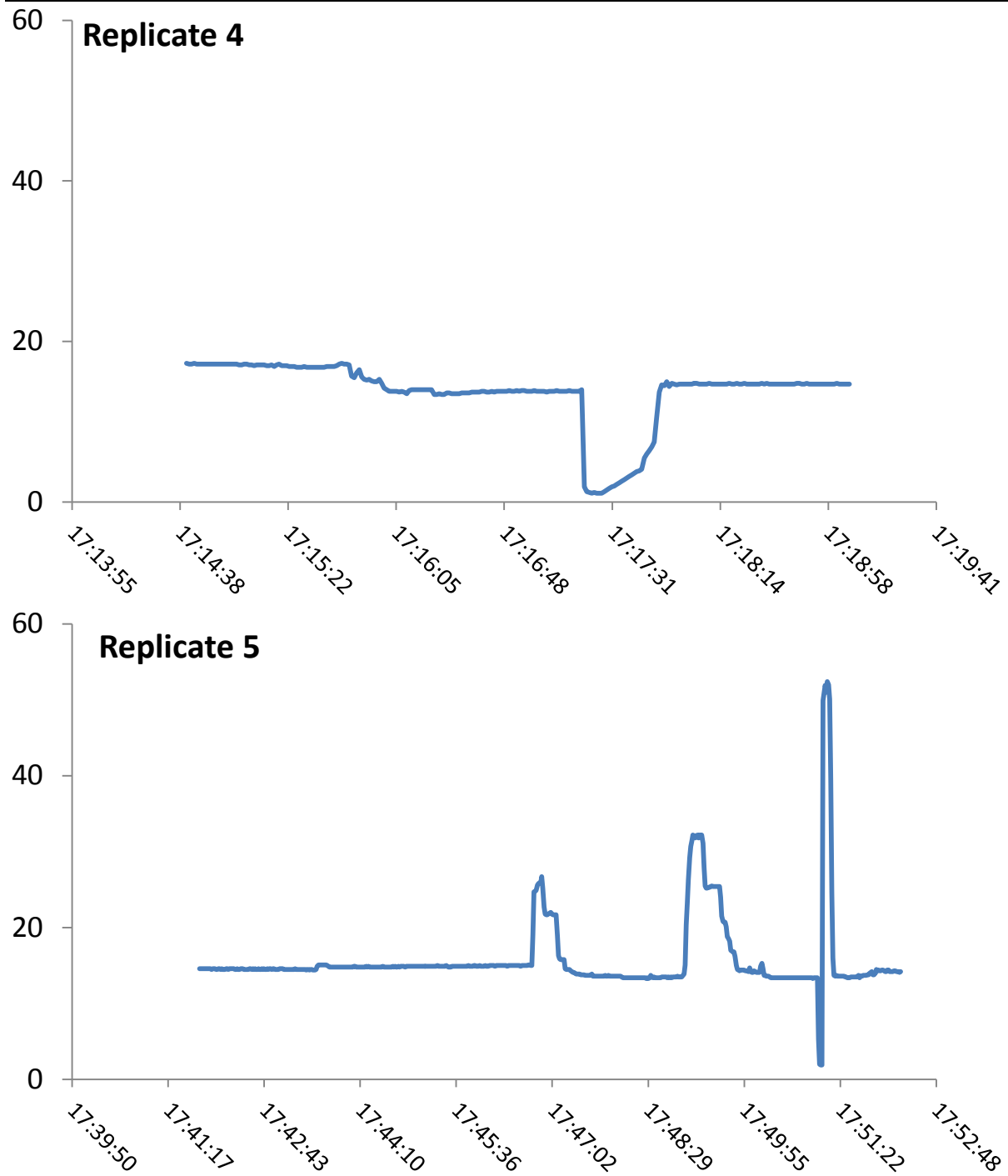


Figure 3.9 (continued). Examples of pressure profiles applied during the decompression replicates for *Pa soi* (*Henichorhynchus lineatus*).

### 3.4 Discussion

Experiments successfully demonstrated that barotrauma is a concern among two Lower Mekong species following decompression to low pressures. There were substantial differences in the biological tolerances of the two species. Snakeheads were far more intolerable to pressure changes than Pa Soi. This could possibly be due to Pa Soi being able to more easily expel gas past the pneumatic duct than snakehead. In addition, Pa Soi may have a stronger and possibly more flexible swim bladder which could lead to less likelihood of swim bladder rupture. Variation in pressure tolerances is largely physiological and depends upon fish size, age, acclimation depth and the ratio of pressure change the individual is exposed to (Brown, *et al.* 2012b, Brown, *et al.* 2013).

Major differences in pressure change tolerances could be expected among different species and sizes of fish. For instance, juvenile sturgeon were not negatively influenced by pressure changes during much of their early life stages when the swim bladder was not yet inflated with air (Brown, *et al.* 2013). In addition, fish with different swim bladder physiology could be expected to respond differently. Physoclists subsequently are likely to experience swim bladder rupture if decompression occurs too rapidly. They may also be more likely to be damaged when internal organs are crushed by the expanded swim bladder. There are many physoclistous species throughout the Mekong, and there is presently no information regarding tolerances to pressure change. It is therefore presently difficult to consider potential impacts on these species when designing small hydro developments.

Exposure to pressures below surface pressure (<101 kPa; 14 psia) was problematic for both species and resulted in substantial mortality. Fish could experience rapid decreases in pressure change at both high and low head dams therefore any project likely to result in a pressure differential needs to consider impacts on fish. Any large pressure decrease would affect fish from the application of Boyles Law, where at a given temperature; a gas will expand when pressure decreases (Brown, *et al.* 2012b). A hydro plant which is likely to produce a large ratio of pressure change should therefore be assessed for potential impacts on fish.

Passage through a gated regulator could also experience rapid decompression. Fish could experience increasing pressure and velocities as the gate is approached. High shear stress would exist at the upstream side of the gate (Baumgartner, *et al.* 2011; Baumgartner, *et al.* 2012a). Passing beneath the gate, would be rapidly decompressed to slightly below atmospheric pressure over a very short distance. Swim bladder expansion would be expected during the process of decompression. Understanding the effects of these pressure changes is important given the many low head structures that either exist or are under construction throughout the Lower Mekong Basin.

The present study had various limitations which may require further consideration prior to the experiments taking place on a large scale. Firstly, future research should consider fish acclimation to deeper depths and given time to adequately become neutrally buoyant (Stephenson *et al.*, 2010). It has been shown that given a fixed nadir pressure (the lowest pressure present during turbine passage) that fish acclimated to deep waters sustain worst barotrauma (Brown *et al.* 2009). Care will need to be taken to ensure that fish are given enough time to become acclimated and that they are not quickly compressed to pressures that are so high that they cannot ever become acclimated. New technology, such as the sensorfish, has also been able to validate pressure changes at dams, thus allowing hydraulic conditions to be accurately replicated under laboratory conditions (Deng, *et al.* 2010). There is substantial confidence that the simulated pressure changes applied in the experimental treatments could be representative of some existing hydro plants.

In addition, pressure profiles generated by the barotrauma units did not suggest a smooth decompression process. The chambers were constructed using manually operated regulating valves. Operators need to coordinate the opening and closing of valves in a coordinated manner to ensure the desired pressure profile is delivered. Other studies have deployed fully automated systems, where desired pressure profiles are computer generated and controlled (Stephenson, *et al.* 2010). The lack of automation led to some variation in pressure profiles including unplanned decompressions and recompressions over a longer time period than anticipated. Fully automating the system is a current priority to increase the accuracy of pressure profiles used in future trials.

It is not realistic to expect that results from these two species to be representative of expected barotrauma in other species with different swim bladder morphology and physiology. International Hydropower Association sustainability guidelines for hydropower development strongly advise application of the precautionary principle to design of new facilities (IHA 2004). Our pilot study provided some preliminary information on two fish species, demonstrating that high mortality could be expected where large pressure differentials exist. For instance, if a new small hydro development were considered for a site of similar operating head where the waterway contained snakehead and Pa Soi then the information provided here is useful because it suggests that pressure changes could create welfare issues.

A major advantage of the barotrauma facility is that experiments can be completed quickly once fish have been acclimated (Stephenson, *et al.* 2010). Considering the ease of use, there is much scope to use the facilities to inform hydro design. For instance, a developer may be interested in considering installation of a hydro unit at a particular dam site. The developer would need to understand certain characteristics like hydrology and operating head to determine the viability of a power generation project. The developer may then be required to prepare a statement of environmental effects if the feasibility study is favourable. Understanding the overall operating head, together with knowledge of local species, provides a good foundation for further investigations. Local fish species could be exposed to a range of expected pressures under controlled laboratory conditions to determine if adverse impacts are likely. Work could proceed according to the precautionary principle if those initial investigations suggested a low likelihood of fisheries impacts. Work could still proceed if adverse impacts were suggested, provided the developer was able to amend the hydro unit design to reduce likely pressure changes. Applying biological data to hydro design in this context is a useful mechanism to demonstrate that due diligence has been applied to potential environmental issues prior to construction commencement.

### **3.5. Conclusion**

Understanding the impacts of rapid decompression on fish have substantial implications for hydropower and regulator design because 1) physical laws govern the behaviour of gases under pressure; 2) Most fish have gas filled structures and 3) All fish that pass through a turbine will experience some degree of pressure change. Exposure to pressures below surface pressure (14 psia) was determined to be damaging to both species assessed. Developers should be encouraged to ensure the required pressure differential to maximise energy generation also protects migrating fish. We encourage engineers, managers, and scientists to work together to develop turbine and infrastructure designs that can apply critical pressure limits to reduce damage to fish while also attain reasonable levels of power generation, turbine efficiency and a broad head range (Brown *et al.* 2012). Critical pressure thresholds can also be used to optimize turbine operations for safe fish passage.

Given the high potential for mortality observed in only two species studied here, our work suggests that pressure change should be a primary factor considered during the small hydro plant design phase. Due to very visible differences in vulnerability to barotrauma, it is suggested that pressure limit criteria based on a small number of fish should not be deemed to adequately represent that of all Mekong River fish. Metrics that can be used to understand the vulnerability to barotrauma should be developed for a wide variety of species. Some important physiological, behavioural and life history traits that could be considered are outlined in Brown et al. in press. These authors also provide a research framework that could be applied to rapidly advance the understanding of barotrauma in the Mekong basin.

We also suggest that future effort be made to increase the capabilities of the NUOL barotrauma facilities. The chambers in place at NUOL were designed mainly for understanding how Mekong basin fish regulate their buoyance. This is critical to understanding the vulnerability of fish to barotrauma. To replicate turbine passage (where pressure rates of change can range from 200 to 900 PSI per second), the current chambers will need to be upgraded or a new system will need to be constructed. This is critical because the rate of pressure change plays a key role in the damage that occurs to fish when they pass through turbines. In addition, Sensor Fish capabilities should be attained to provide regular calibration of chamber pressure sensor systems.

## 4. Using shear and barotrauma facilities to develop mini hydro design criteria

### 4.1. Procurement of a shear flume

The procurement of a shear flume is a substantial achievement for fish passage in the Lower Mekong Basin. It will, for the first time, enable the effects of shear to be determined for Lower Mekong species and be practically applied to future hydro development projects. Results could be more generally applied to other river infrastructure such as sluice gate design and river diversions.

Immediate actions to maximise use of the new facilities include:

1. Benchmarking existing levels of shear at existing river infrastructure to determine limits likely to affect fish (i.e. Figure 4.2, Figure 4.3)
2. Performing additional shear experiments on other Mekong species, including adults, juveniles and larvae
3. Consider experimentation to determine if injury risk changes with different fish orientation (head first or tail first). If there is substantial difference then it will be essential to provide conditions at river infrastructure which support fish aligning with the preferred orientation
4. Organising training in both the USA and Australia for Lower Mekong scientists responsible for understanding environmental impacts of river development
5. For NUOL to developing a research use agreement for existing facilities so they are made available to other research organisations and development agencies.

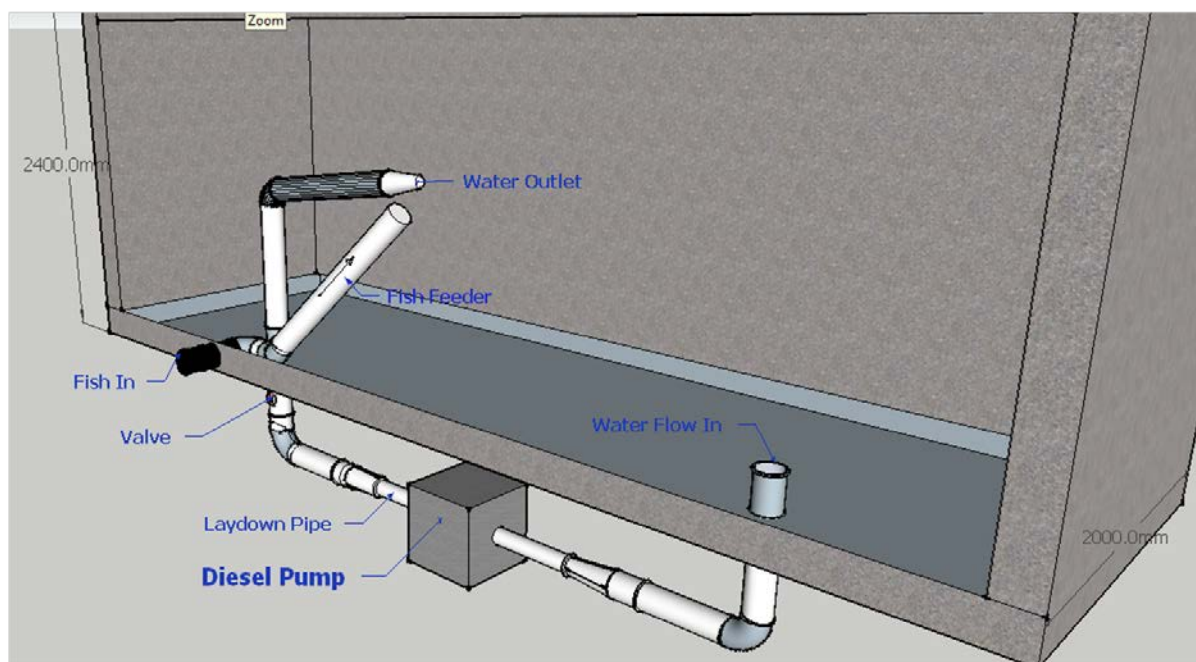
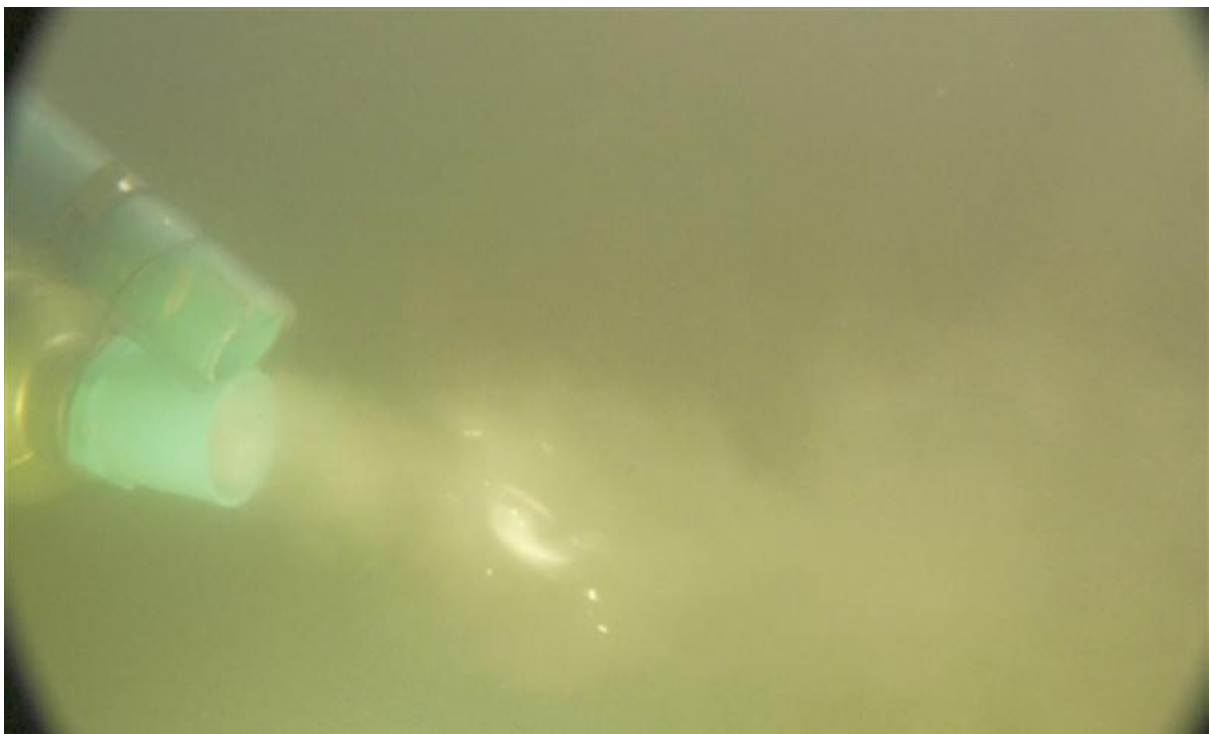


Figure 4.1. Sketch of recently completed shear flume installed at Dongdok Campus in Lao PDR.



**Figure 4.2. Example of opercular flare, causing potential gill damage, of a fish exposed to a high velocity jet at new facilities installed at the Dongdok campus.**



**Figure 4.3. Example of scale loss from a fish exposed to a high velocity jet at new facilities installed at the Dongdok campus.**



## 4.2. Procurement of a barotrauma facility

Barometric chambers are highly specialised scientific apparatus that require specialised training (Stephenson, *et al.* 2010). The physics concepts underpinning the operation of these units, and the resultant physiological impacts on fish require specialist scientific treatment. The procurement of barometric chambers is a substantial advancement for river infrastructure research in the Lower Mekong Region. All fish that pass under a sluice gate or through a hydro plant will experience a pressure change. Some will experience substantial decompression and it is inevitable that some will experience barotrauma. The units will help to understand the causal factors leading to barotrauma, which in turn will help to craft an engineering solution that can be applied to new projects including:

1. Benchmarking existing levels and rates of pressure change at existing river infrastructure to determine limits likely to affect fish. This should include the use of either sensorfish or CFD modelling or preferably both.
2. Determining likely ratio of pressure changes that fish may experience over a range of different structures
3. Performing experiments on other Mekong species, including adults, juveniles and larvae under conditions which mimic expected pressure profiles at river infrastructure
4. Upgrading the chambers if needed to allow them to decompress the fish with at the very rapid rates present during turbine passage.
5. Organising training in both the USA and Australia for Lower Mekong scientists responsible for understanding environmental impacts of river development
6. For NUOL to developing a research use agreement for existing facilities so they are made available to other research organisations and development agencies.

## 4.3. Supporting equipment

Laboratory studies are excellent for reductionist studies to understand the contribution of individual stressors to injury and mortality. Outputs can be used as a first starting point for the development of specific design criteria which could be applied conservatively to new developments. These studies, however, fail to account for complex interactions among hydraulic stressors which are likely to occur in field situations. It is therefore important that these facilities, be used to complement other techniques that can help to understand the hydraulic environment within hydro systems. Other techniques that need to be acquired include:

Computational Fluid Dynamics (CFD): These refer to a complex series of hydraulic models that can predict flow, turbulence, shear and pressure changes based on the physical properties of water. CFD models are useful because they do not require expensive physical models to understand flow characteristics and can be run quickly and efficiently using desktop methods. Expanding capacity for CFD modelling throughout the Lower Mekong Basin would help to make more informed decisions regarding hydro development.

Sensorfish: Sensorfish are complex electronic devices which are used to measure the conditions present when fish pass through turbines or other water infrastructure (Deng, *et al.* 2007a) (Figure 4.4). Sensorfish contain gyroscopes, pressure sensors, and accelerometers which can take up to 2000 readings per second (Deng, *et al.* 2007a) (Figure 4.5). Units can be deployed into hydroplant draft tubes and, when retrieved, can provide a detailed understanding of the hydraulic environment. Studies that combine sensorfish data with live fish passage success can provide powerful understanding of potential welfare issues.



Figure 4.4. Scientists about to deploy a sensorfish to investigate the pressure and shear profile of an undershot regulator in Lao PDR (Photo courtesy of Dr Craig Boys).



Figure 4.5. Paksan district fisheries officer with a sensorfish, a small automated device capable of recording up to 2000 pressure, pitch and roll readings a minute (Photo courtesy of Dr Craig Boys).

Dual Frequency Identification Sonar (DIDSON): The DIDSON is an acoustic device which converts sound waves into a digital image. It can be deployed underwater for any period of time and is effective in both clear and turbid water. DIDSON is particularly effective for identifying objects underwater and documenting specific aspects of fish behaviour (such as accumulations, avoidance behaviour or predation). The use of a DIDSON can also be correlated with flow data to determine how fish behaviour changes under specific discharges. These units are widely used in hydro passage studies in North America.

The acquisition of supporting equipment will assist with long term studies beyond the pilot phase. Whilst having a detailed set of equipment is needed to inform engineering and development agencies, there is an equally pressing demand for skilled, trained and experienced scientists. The International Energy Agency recently announced the formation of a Fish and Hydro Research Annex which represents a global initiative seeking to progress mitigation options at hydro facilities. It is a unique global opportunity where scientists collectively working on the same issue are collaborating to bring about global outcomes. The Lower Mekong Basin was represented on this group at the inception meeting, but there are no further plans to send delegates for the remainder of the activity period (2013-2016). Ensuring regional participation and using the opportunity to educate and extend activities more widely within the Lower Mekong region would be of substantial benefit during a time of unprecedented river development.

#### **4.4 Application to industry**

The ultimate aim of this project was to provide equipment and information that can be applied to industry with the overall aim of improving hydro and irrigation infrastructure design. Developers and engineers must make use of the equipment and generated data for this project to have positive overall impacts. Publications on thresholds in reports and international journals are useful but it is gaining appreciation for the data by design engineers that will ensure uptake across a large spatial scale. A major challenge in extending results from this work will be ensuring that new developers are made aware of this information.

Regional agencies such as the Mekong River Commission are important sources of extension and conduits for information. There is an urgent need for government regulation of development activities. Many countries in the world have well defined processes that require consent approval, based on environmental considerations, prior to work commencement. Whilst this does exist in the Lower Mekong it is inefficiently applied among governments and projects. A standard process for all riparian governments would certainly assist, and data generated from this project could inform that approach. The end point of such a strategy would be development that is based on the best available science, using world-class construction techniques that mitigate the overall impacts on fish and other aquatic fauna. Having high quality scientific results is an essential first step to initiate this process, but should be adaptively applied to new projects as additional knowledge is generated.

To assist development goals, several recommendations follow from this work include:

1. That further funding be obtained to increase the number of species where hydraulic information has been obtained
2. That a database be established and contains information on tolerances of hydraulic information for Mekong fish. The database should be centrally housed on a platform that is open and available to researchers, managers and developers (possibly through the MRC or Mekong Information Network).

3. That a consistent approach for consent approval be developed and implemented throughout the Lower Mekong Basin
4. That the existence of the new facilities and the preliminary data be extended to donor bodies and developers through a regional hydropower sustainability workshop that comprises representatives from all riparian countries
5. That the existing equipment and data be used as leverage for future funding opportunities to expand the existing knowledge base of the effects of shear stress and pressure changes on fish
6. That preliminary data be used to progress the construction of a hydro facility on a tributary stream. The proposed plant should be validated using complementary techniques and live fish experiments to determine fish-friendliness.

## 5. Good practice guidelines for fish friendly mini hydro development in the Lower Mekong Basin

### 5.1 Background

#### 5.1.1. Need for this document

Nearly 30% of the world's population has no access to electricity. Most energy generation is based on fossil fuels and account for a significant proportion of gas emissions leading to global warming. Hydropower is a major renewable energy source that can help global communities meet sustainability objectives. Many countries recognise the need for hydropower of all scales to increase the overall contribution of renewable energy at a global scale. There is general acceptance that hydropower can significantly contribute to sustainable development, provide access to energy, assist the poor, mitigate greenhouse emissions, reduce air pollutants, mitigate flooding and reach areas that grid systems cannot traditionally reach. It is essential that any potential hydropower development considers environmental outcomes, in addition to economic and social, from inception. The role of this document is to provide a succinct introduction to the major considerations for any hydropower development that can enable rapid assessment of potential environmental considerations well before the detailed design phase and after construction is finalised. This particular document has a strong focus on hydropower issues relating to fish. Like any guidelines, this document aims to provide guidance for:

1. Policy development
2. Government decision making
3. Helping developers to understand requirements
4. Ensuring environmental considerations are addressed

Most countries have active guidelines for hydropower which consider triple bottom line outcomes. The hydropower industry largely recognises inter-relationships between these three beneficiaries but it is important that all are considered equally at an early stage. Addressing these concerns early in the process can avoid much greater costs mitigating these issues into the future. A core, and fundamental principle to be applied is the precautionary approach. IHA guidelines state that the precautionary principle should be guided by:

- Evaluation to avoid serious or irreversible damage to the environment
- Consideration of the need for electricity and a reliable water supply to alleviate poverty and enhance living standards
- An assessment of risks associated with various options

Accepting application of the precautionary principle allows for development to proceed in the absence of all required data to mitigate a risk. Developers should take stock of all available information at any given time to ensure that environmental obligations are being met.

#### 5.1.2. Hydropower and sustainability – a global perspective

The impacts of hydropower on fish have provided mixed experiences on a global scale. Many countries have reported substantial declines in rivers that have been developed for hydropower, and some, for instance the Columbia River in USA, have require substantial investment to prevent further declines. Many governments now have legislated responsibility for protecting fish at hydropower installations and require either engineering or operational mitigation measures. In some cases government has

removed a hydro dam because the cost of meeting environmental obligations has exceeded the overall capital cost and concurrent revenue.

Hydropower projects impact fish populations in several different ways:

1. It can block upstream migrations
2. It can block downstream migrations and lead to injury and mortality during downstream passage
3. It alters riverine habitat to slow flowing lake habitat, which does not suit all species
4. It can alter the flow regime, thus eliminating cues for migration and spawning
5. It can impact water quality

Practical examples of how these factors impact fish are well documented in the literature. Blocking upstream migrations can prevent fish from accessing spawning and feeding habitat. It can also lead to unnatural high density accumulations downstream of hydropower projects which lead to increased disease and predation. Obstructing downstream migrations can be detrimental to fish like salmon smolt, which must reach the ocean. Passage through turbines and spillways can also lead to injury or mortality, which is the case with Eel migrations in Europe. Changing from river to reservoir habitat has resulted in the local extinction of riverine species in some areas; and the total replacement of fish communities in others. Modifications in downstream flow regimes have eliminated cues for important upstream migrating fish. Thermal stratification within reservoirs can lead to depressed or increased temperatures which can either kill fish, or create conditions that do not support spawning or other important life history processes.

Many of these impacts can be mitigated with forward planning and a pro-active approach to design and construction.

### **5.1.3. Hydro development in the Lower Mekong Basin**

Hydropower is the most rapidly advancing development area in the Lower Mekong Basin at present. There are many high level dams proposed and many smaller-scale hydro developments planned for lower head structures. It has been estimated that the combined effects of existing dams will reduce fish catches by between 150,000 and 480,000 tonnes between 2000 and 2015 (ICEM 2010). Tributary dams alone are predicted to reduce total fish stocks by 10-26% by 2030 (Orr, *et al.* 2012). In addition, it has been estimated that to replace consumed fish protein with domestic livestock protein would require an additional 63% of pasture lands and 17% more water (Orr, *et al.* 2012). It is clear that river development is expected to have a substantial impact on the Mekong and its fish resources.

Fish are an extremely important commodity in the Lower Mekong Basin. Fish account for much of total animal protein consumed by Lower Mekong river communities. The MRC mainstem hydro guidelines (MRC 2009) document specifically identifies fish as requiring special consideration in dam design. It states:

“Effects on the fisheries resources of the Mekong, the world’s largest inland fishery, especially the barrier effect that dams could have for migratory species, fish biodiversity and the subsequent consequences for people’s livelihoods”

There are no formal design criteria for acceptable fishways, downstream passage facilities or hydro dam operations for hydro developments in the Lower Mekong Basin, therefore developers should apply the precautionary principle whilst using the best available science.

#### 5.1.4. Mini hydro potential

The 1995 Mekong Agreement (MRC 1995) makes specific mention that the MRC needs to:

“Formulate a consistent approach to evaluate the design, operation, impact and mitigation measures for any proposed mainstream dam in a basin-wide, sustainable development context”

The Mekong agreement largely discusses mainstem hydro. However, the development of tributary streams can also have impacts. Further, the development of mini and micro hydro units on the thousands of other smaller barriers are likely to impact fish if appropriate measures are not taken. Many new low head systems are now commercially available and could have potential application on tributary streams or be retrofitted to existing river infrastructure.

#### 5.1.5. Standardisation of approaches

The Mekong River Commission established the Initiative on Sustainable Hydropower (MRC 2010) to advance and clarify thinking about the sort of cooperation that is needed among Mekong countries to sustainably manage the growing number of existing hydropower assets in the Mekong basin. The cumulative trans-boundary effects of these projects will inevitably be felt and need to be linked with wider strategies for sustainable development in the regional power sector as a whole. This guidance therefore seeks to establish a set of agreed minimum considerations that could be applied at a regional scale when considering the impact of mini hydro facilities on fish communities. Consistent with mainstem initiatives, initial focus should be avoidance of impacts, rather than mitigation (MRC 2010).

### 5.2. Relevant governmental processes for approval of small hydro

Legislation governing the installation and operation of the hydropower sector were reviewed and documented in detail as part of CPWF project MK1 (Suhardiman, *et al.* 2011). Six different policy cluster sections were identified that were relevant to hydropower development including:

1. General Policy
2. Energy-related policies
3. Water resources management
4. Environmental protection
5. Land Management
6. Resettlement and compensation in development projects

The linkages among these policy areas are complex, and the relationships with ministries responsible for regulating implementation, within the Hydropower context, is confusing. A replication of the detailed analysis is not needed here, but an overview of issues specific to fish in each country is presented.

#### 5.2.1. Lao PDR

The Lao Renewable Energy Development Strategy identifies a potential 2,000MW production potential from Small hydropower projects (less than 15MW). It recognises that there were difficulties with small hydro in the past due to natural disasters, poor management and a lack of financing for maintenance and technical support (Lao 2011). A legal framework for the development of Small hydro is due for delivery in 2016. The Draft Water Law (2013) specifically states that the ecosystem services provided by wetlands must be recognised and protected (Article 41) in addition to the identification of Water Resources Protection Zones (Article 46) (Lao 2013). However, this draft

legislation is awaiting ratification into Law. In the meantime, most development projects are governed by the Environmental Impact Assessment Decree (2010).

The EIA decree addresses development projects in one of two categories:

1. Category 1: Investment projects which are small or have little expected environmental impact. These generally only require initial environmental examinations (IEE)
2. Category 2: Large complex projects which, due to large expected environmental impacts, require a full Environmental Impact Assessment.

Under the EIA decree, developers must ensure public participation and discussion with local administrators from the district and province (Wayakone and Makoto 2012). There is a general absence of independent regulatory bodies in Lao PDR and in general, a development activity may need to pass through several different ministries (Wayakone and Makoto 2012). Each ministry administers different laws and aspects of each need to be incorporated into the approval process. However, in practice, most fisheries management and mitigation activities are carried out at a local level and community management frameworks are common.

The general process for commencing with a hydropower project in Lao PDR is (Suhardiman, *et al.* 2011):

1. Signing a Memorandum of Understanding (MoU) between private investor and the Ministry of Planning and Investment to conduct feasibility study.
2. Proceed with feasibility study with private investor as the lead actor.
3. Presentation of feasibility study results to Department of Energy Promotion and Development at Ministry of Energy and Mines.
4. Negotiation of Concession Agreement (CA) between private investor and the Government of Laos led by Ministry of Energy and Mines.
5. Parallel to this private investor submit Environmental Impact Assessment (EIA) report for approval from relevant Environment Ministries.
6. Negotiation of Power Purchase Agreement between private investor and power purchaser (following the signing of the CA and EIA approval).
7. After the signing of PPA, private investor will start with necessary preparation for dam construction both technically and socially (regarding resettlement, compensation).

Impacts on fish and environmental obligations would be determined as part of the feasibility study. This is when detailed thought should be given to impacts and possible mitigation options. If the project falls into Category 1 of the EIA decree, then the Government of Lao will ultimately decide whether a CA, EIA or PPA will be required.

### **5.2.2. Vietnam**

The Vietnamese Government introduced the Strategic Orientation for Sustainable Development (2004) in an attempt to align with United Nations frameworks. Development of relevant legislation to support this strategy has been slow. The Law on Environmental Protection (1993) provides for protection of the environment whilst attempting to promote sustainable development. The law was revised in 2005 to specifically provide enhanced opportunities to manage river basin areas, protect biodiversity and encourage the development of environmental technical standards. The Government of Vietnam performed a Water Sector Review (2010) to identify where water shortages may occur, but the review did not consider impacts on fish in detail. The Fisheries Development Strategy was



subsequently developed to protect fish. The development of an Intact Rivers Policy, including provision for fish passage, has been touted as a potential mechanism to include specific provisions for fish (Carew-Reid, *et al.* 2010).

Hydropower planning occurs at three different levels, each with distinct stages (Suhardiman, *et al.* 2011). The general process includes:

1. Developing a hydropower masterplan which fulfils all legal requirements for each river basin which is endorsed by the Ministry of Investment and Trade.
2. The plan will include a list of specific projects which will determine the maximum level of development permissible to exploit a catchment for hydropower
3. Develop a detailed investment proposal for each potential project
4. Investment plan is endorsed by the relevant Provincial Peoples Committee (PPC)
5. Licencing is arranged with the relevant Ministries
6. Contracts must be approved by government prior to commencing construction.

Ideally, all potential impacts on fish will be documented in the masterplan, but if not, it would need to form a substantial component of the investment proposal, as that would need to contain details on relevant mitigation measures and options.

### **5.2.3. Thailand**

Thailand has the longest history of Hydropower development in the South East Asian region. Construction began in the 1960's and dozens of large head projects were completed in subsequent decades. Thai citizens became increasingly concerned about the progressive loss of farmland, villages and forests arising from hydropower reservoirs which led to the cancellation of the Nam Choan project (Phonpaichit 2000). The 'run of river' Pak Mun project was then completed in 1994 and led to large scale protests by villagers whose fishing livelihoods were impacted (Amornsakchai, *et al.* 2000). It should be noted that the Environmental Impact Assessment of Pak Mun actually stated that fisheries production would increase in the reservoir and stated that a fishway would not be necessary (Amornsakchai, *et al.* 2000). The project eventually led to the disappearance of 50 species whose spawning grounds were inundated by the reservoir (Amornsakchai, *et al.* 2000). There was a further decrease in abundance and biomass of another 51 species (Amornsakchai, *et al.* 2000). Since then, few large projects have been initiated in Thailand and the major focus has been on importing power from neighbouring countries.

The development of new hydropower projects in Thailand generally requires approval from several government agencies. The Thai National Environmental Quality Act (1992) identified 34 different scales of project development which may require an environmental impact assessment (Liاملen, *et al.* 2013). For dams and weirs, the main classification is based around the size of the intended reservoir. The impact assessment process is usually overseen by the Environmental Impact Evaluation Bureau, Office of Natural Resources and Environmental Policy and Planning and the Ministry of Natural Resources.

The general process includes (Liاملen, *et al.* 2013):

1. Project proponent identifies site
2. Feasibility study commenced
3. Environmental Impact Assessment drafted

4. Submission of a project to the Office of Natural Resources and Environmental Policy and Planning (ONEP) and relevant permitting agency.
5. ONEP makes preliminary comments on EIA
6. EIA referred to an expert review committee and comments are given
7. Public consultation performed
8. EIA revised and resubmitted
9. Decision is made and comments publically published on Thai government websites
10. The proponent has a 90 day appeal period if the review is not favourable

Impacts on fish should be captured in the EIA including mitigation measures and expected impacts. However, the assessments of impacts can only be successful if detail contained within the EIA is accurate. Incorrect information led to the approval of Pak Mun which consequently had adverse ecological impacts. Similarly, the recently completed Lamtakong Hydropower Project led to overall declines in fisheries productivity despite following relevant approval processes (Liamlen, *et al.* 2013). These examples suggest that criteria considered during the EIA process may not be conservative enough to protect fisheries resources in Thailand.

#### **5.2.4. Cambodia**

Projects in Cambodia are managed by Environmental Impact Assessment processes which are largely overseen by the Ministry of Environment (Baran 2005). Fish passage is a key criterion to be addressed via this process (Hortle, *et al.* 2004). It is noted that environmental changes caused by smaller developments do not require an EIA so other measures are often needed to protect fisheries (Hortle, *et al.* 2003).

The general decision making process for hydropower projects in Cambodia includes (Suhardiman, *et al.* 2011):

1. Seeking approval for any project to be included in the national power generation expansion plan which requires a submission to the prime minister, deputy prime minister, a member of the Council of Ministers or the Minister of Economics and Finance
2. If approved, the project is considered by the Council for Development of Cambodia
3. If approved, the project then proceeds to Ministry of Industry, Mines and Energy so that a memorandum of understanding can be drafted in order to receive a formal letter of permission.
4. The letter of permission is valid for two years and allows for the preparation of feasibility studies and the development of an Environmental Management Plan. It is expected that this will be self-financed by the proponent.
5. The feasibility study is then presented to Ministry of Industry, Mines and Energy for further discussion and final approval. MIME will determine if a full environmental Impact Assessment is required. It usually occurs after the Department of Environmental Impact Assessment or provincial environmental officers visit the site and discuss with the proponent.
6. Impact assessment is reviewed by relevant government departments.
7. The project is approved by the Prime Minister's Office
8. After construction the proponent is expected to fund a monitoring team to ensure the environmental obligations are being met.

Impacts on fish and potential mitigation measures must be included in the impacts assessment documentation or environmental management plan (whichever is relevant). The Cambodian

government deems any project expected to generate more than 1 Megawatt as potentially having an environmental impact. So most small hydro projects in Cambodia will be required to have some degree of environmental management plan developed. Designs and options for mitigation devices would be captured as part of that process. Effectiveness would then be monitored upon completion.

### **5.3. Biological and ecological considerations**

#### **5.3.1. Seasonality and fish migration**

Many lower Mekong species are highly mobile. Many fish species perform long distance migrations which include traversing large distances in the main channel and also into tributary streams. Flow in the Lower Mekong Basin is separated into the 'rainy' and 'dry' season. Some species have adapted specialist life history stages which account for varying hydrology. For instance, some species will actively migrate upstream during high flow periods, including gaining access to wetland habitats. In addition, during the dry season fish may seek out refuge pools. It is important that such migrations are not impeded by hydro development

Hydropower installations on rivers containing migrating fish species should be subjected to special requirements to minimise impacts. Key issues for migratory species:

1. To protect spawning areas
2. To provide seasonal flows provided to enable spawning to occur,
3. Allow adequate residual flow is maintained over the weir to maintain ecosystem processes (i.e. No unseasonal zero flow periods),
4. That an upstream migration route is provided
5. That safe downstream passage is provided

#### **5.3.2. Upstream migration**

Hydropower schemes are typically associated with impounding structures that impede fish movements. In almost all situations, a new hydropower scheme will need to address fish passage. A scheme should not make it more difficult for a fish to move upstream. Under such situations a functional fishway or fishways must be provided. If there is insufficient biological data to determine whether migratory species are present, a fishway should be constructed according to the precautionary principle.

General guiding principles to ensure a functional fishway is constructed include:

1. Selecting a design that is appropriate for local species. Ideally the design will have previously been assessed as being suitable which has been validated by scientific studies
2. Ensuring the fishway is operational for 100% of flows experienced at the site
3. Ensuring entrance and exit location are fully optimised to maximise fish passage
4. That the full complement of species and size classes requiring passage can ascend
5. That there are no delays in migration for fish attempting to pass
6. That an operations and maintenance plan are developed to ensure long term functionality
7. That the fishway has an effective operating life equivalent to the mini hydro plant
8. A need to perform compliance monitoring (including hydraulic assessment) to ensure the fishway is meeting all design specifications

#### **5.3.3. Downstream migration**

Most species of freshwater species move downstream at some stage of their life. The need may vary from a large scale co-ordinated fish movement, to passively drifting larval stages, to movement from

a floodplain wetland back to a main channel. Irrespective of the need to migrate, provision of a downstream pathway is paramount to effective maintenance of longitudinal connectivity at a small hydro plant. The scale of downstream passage facilities will be dependent on the size and type of hydro facility, site hydrology, target species and discharge method (all via hydro plant, spillway, bypass system or notched weir). Considerations to protect downstream migrations include:

1. Identifying whether bypass systems can be installed
2. If bypass is not an option, appropriate screening devices may be required to exclude fish from areas of harm.
3. Screens should, as a minimum, protect the smallest expected migrating fish at the site. By default, all larger fish should then be protected and there should be no risk of fish impingement. But for eggs and larvae, safe passage through the turbine would be more practical than installing fine mesh screens which may foul or reduce discharge.
4. If screening is not possible, then safe passage through the hydro unit must be ensured (but this is the least preferred option).
5. Safe hydro unit passage will require understanding of pressure profiles, fluid shear levels and expected blade strike probability
6. Appropriate mitigation measures for downstream passage must be based on best available science. If little information is available, best practice techniques based on the precautionary principle should be applied.
7. The overall aim of downstream passage protection should be no injuries, no mortality and no migration delay
8. The life of downstream passage mitigation techniques must equal, or exceed, the planned life of the hydro unit.
9. An operations and maintenance plan should be developed and implemented
10. Effectiveness of downstream passage techniques should be quantified and validated at every site.

#### **5.3.4. Water quality**

Negative effects on water quality are an indirect impact from impounding waterways which can have a direct impact on fish. At larger dams, thermal stratification could be a major impact following construction. Thermal stratification occurs when there is insufficient mixing in the impoundment (Todd, *et al.* 2005). Surface water becomes heated but bottom water stays cool and may become anoxic. There can be often be several degrees difference between surface and bottom water (Sherman, *et al.* 2007). When water is released from a bottom release valve, downstream temperatures can be suppressed for many kilometres (Preece and Jones 2002). Suppressed temperatures can decrease egg hatch rates, eliminate migration cues and prevent spawning altogether (Rolls, *et al.* 2013; Todd, *et al.* 2005). The opposite can occur in cooler climates where bottom temperatures are much higher than surface temperatures, but this is less likely to be an issue in a tropical system such as the Mekong.

Thermal pollution can be predicted based on the height, location and anticipated operating protocol of a dam or weir. To deal with thermal pollution risk, it is essential to:

1. Perform a risk assessment of likely impacts on thermal regime following dam or weir construction
2. Determine whether operation of a mini hydro plant is likely to lead to bottom releases

3. Identify whether engineering solutions are available to prevent stratification (aeration, surface mixers, multi-level offtakes, thermal curtains)
4. Ensure that options to control thermal pollution are included in operations and maintenance of new structures
5. Ensure that the lifespan of mitigation measures equal or exceed the life of the hydro unit
6. Ensure a monitoring program is in place to deal with stratification and that operations are changed accordingly whenever stratification occurs

### **5.3.5. River discharge and flow**

Hydropeaking is the rapid changes in flow downstream of hydropower plants and is an unavoidable phenomenon when water is harnessed for power generation (Gostner, *et al.* 2011). During periods of high power demand, river flows will rise abruptly (Yellen 2012). When demand falls, river levels will drop. Such variations occur naturally in the Mekong River, with a natural cycle of wet and dry seasons leading to large level variations (Lauri, *et al.* 2012). These occur on a seasonal basis. In hydropeaked rivers, these natural variations can occur on a daily basis (Yellen 2012). Such variations can substantially interfere with flow-dependent fish species. For instance, fish cued to migrate by changes in flow would have natural cues interrupted. Species which nest on inundated vegetation could have eggs exposed when river levels rapidly drop. Habitat availability could substantially change. Thermal regime could change if the reservoir associated with the hydro plant is stratified. When considering construction of a mini hydro system, the following factors should be considered:

1. Will hydrology be substantially modified?
2. What are the expected maximum daily fluctuations?
3. Will flow dependent species be affected?
4. Can operational rules be created which prevent hydropeaking?
5. Are engineering solutions to divert peaked discharges available?

## **5.4. Fish Friendly turbine design principles**

### **5.4.1 Types of injury and mortality that could be expected**

Injury and mortality within hydro power systems generally arise during downstream passage. Due to high velocities and turbulence profiles, fish will be unable to move upstream through a turbine. If fish are not appropriately excluded from turbine passage they may experience injury or mortality from several mechanisms (Čada 2001):

1. Rapid and extreme pressure changes (water pressures upstream of the turbine may increase to several times atmospheric pressure, then drop to sub-atmospheric pressure, all in a matter of seconds),
2. Cavitation (extremely low water pressures cause the formation of vapour bubbles which subsequently collapse violently),
3. Shear stress (forces applied parallel to the fish's surface resulting from the incidence of two bodies of water of different velocities),
4. Turbulence (irregular motions of the water, which can cause localized injuries or, at larger scales, disorientation),
5. Strike (collision with structures including runner blades, stay vanes, wicket gates, and draft tube piers), and
6. Grinding (squeezing through narrow gaps between fixed and moving structures).

The severity (and possibility) of each is largely dependent on the species requiring passage, structure height, operating regime and turbine design (Larinier 2008). For instance, eel mortality in France is

highly dependent on turbine design. Francis turbines rotate at a much higher speed, and are installed at higher operating heads, than Kaplan turbines and contribute to high blade strike mortality. Mortality rate has also been highly correlated with both fish length and turbine design (Larinier 2008).

Salmon species experience substantial welfare issues in the Columbia River Basin (USA) (Williams 2008). Some of the most detailed experiments globally have been conducted at sites where downstream passage of smolt is of high conservation concern. Over \$US7 billion has been spent on efforts to minimise salmon injury and mortality in the past 5 decades which demonstrates the substantial expenses required if fish welfare is not considered during design and construction.

Many aspects of injury and mortality could be addressed during the design phase. For instance, pressure changes could be mitigated by reducing the overall head differential across the structure or deploying a turbine design which minimises pressure differentials across runner blades. Fluid shear can be reduced by using fish-friendly runner blades or by improving draft tube design to promote laminar flow. Physical strike can be minimised by employing designs that minimise draft tube velocities or by increasing runner blade spacing. Considering the target species composition during the design phase can greatly assist with the selection of turbine designs that can minimise fish-related impacts.

#### **5.4.2. Commercially-available fish friendly units**

Concerns over potential impacts of hydropower plants on fish have led to the development of several designs which claim to minimise or eliminate fish-related impacts. The US Department of Energy, recognising the impacts of hydropower generation on fish, commissioned the development of fish-friendly designs (Odeh 1999). Work sought to improve existing runner designs and also develop new designs that eliminate impacts on fish altogether. Concurrently, a study commissioning the development of biological design criteria sought to identify the major factors contributing to fish injury (Cada, *et al.* 1997). The report clearly outlines the major impacts on fish and the factors that need to be considered when developing mitigation options. These guidelines are not intended to make recommendations on which particular commercial design may be best. This is likely to vary among designs and specific installations. Here we seek to outline the types of considerations which may help a developer select a design at a site where conservation of fish is an intended outcome.

The decision to proceed with any given design may depend on many factors. It may be decided to proceed with the installation of an untested turbine provided the developer is open to discussions about adaptive research strategies to validate and enhance fish friendly attributes. Under these circumstances consent agencies may agree to installation of a 'pilot' structure on a site of low conservation significance provided post-construction monitoring is possible. Specific decision making considerations include:

1. Has the design considered biological impacts?
2. Have the needs of Mekong species been considered?
3. Are laboratory tests available?
4. Are hydraulic model data available?
5. Has one been installed in the past and validated?
6. Is the developer open to discussions on mitigating ecological impacts?
7. Is the developer open to the possibility of post-construction monitoring?
8. Has the selected turbine been assessed for safe fish passage using local species?

### 5.4.3. Assessments of fish friendly designs with non-salmonid species

Relating criteria developed for salmonids with those of non-salmonid fish is problematical (Cada, *et al.* 1997). Anadromous salmonids have specific life history stages that require a seaward migration at an early life history stage and a subsequent upstream spawning migration after maturity (Cada, *et al.* 1997). These fish have well established migration requirements and the needs for both upstream and downstream movement can be predicted with some degree of certainty. Hydro plants have also been responsible for the dramatic collapse of several iconic salmon species (Williams 2008). In an effort to arrest declines and understand the mechanisms involved, most knowledge on the impacts of hydro plants on fish have been based on studies with salmonids.

Salmonids have unique physiological, biological and morphological characteristics that are not directly applicable to other species. Applying salmonid criteria to the design of upstream facilities led to the ultimate failure of several fishways constructed in Australia (Mallen-Cooper and Brand 2007). Salmon were able to negotiate higher velocities and turbulence than most Australian fish. It was not until targeted research was performed on Australian species that highly successful designs were developed (Mallen-Cooper 1996). It is likely that the application of downstream criteria would be equally unsuitable. Salmonid species migrate downstream during the smolt phase when most fish are typically over 10cm long (Riddell and Leggett 1981). But many Australian species move downstream as larvae (Gilligan and Schiller 2004). Salmonid criteria for screening and diversion velocities are therefore also unlikely to be applicable.

A similar situation will exist in the Mekong where an estimated 900 fish species exist. Fish species vary in their response to upstream and downstream fish passage conditions. So design criteria need to be investigated species by species and adaptively applied to new projects. As new information is developed, future designs can be improved to optimise fish passage and contribute to triple bottom line outcomes.

### 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 can be used on a maximum slope of 1:20 and is designed to simulate natural stream pools and falls, or riffles. 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.

#### 5.4.5. Downstream fish passage options

A major fish passage issue at mini hydro facilities will be downstream passage. There are generally four options for protecting downstream migrants:

1. *Fish pass through the turbine directly.* If all hydraulic criteria for safe passage can be met, this is the most cost effective way of providing passage provided it complements fish behaviour.
2. *Constructing screens to totally exclude fish from moving through the turbine.* Whilst this can minimise damage it can introduce a downstream migration barrier. Care also needs to be taken to ensure turbine mortality is simply not transferred to the screen where fish can become impinged. Many existing screening systems, such as those constructed in the USA, primarily screen the surface layer because this is where most fish approach the hydropower unit. However, in the Mekong there are many benthic fish species (such as catfish) so it is important that screening facilities are specifically-developed for Mekong species. It will be difficult to screen eggs and larvae so sites where high drift rates are expected will need to contain friendly turbine designs.
3. *Ensuring fish move downstream via the weir crest or spillway.* If a spillway (whether a deep spill spillway or surface skimming spillway) or weir crest is present it may be preferable to divert fish away from the turbine intake and to a more appropriate location for downstream passage. It is important that for crest and spillway passage, that the operating authorities ensure sufficient depth under all scenarios to allow fish to pass. Smooth gentler sloping spillways are preferred as are overshoot weir crests which contain a downstream plunge pool to minimise the risk of physical strike. Stepped spillways can create impact zones which are known to damage fish and should be avoided. Care also needs to be taken at deep release spillways to ensure fish are not exposed to high rates of pressure change which could lead to barotrauma.
4. *Through specially constructed downstream migration facilities.*  
Some sites will contain turbines where conditions for safe fish passage cannot be guaranteed. Similarly, these sites may also lack an effective spillway or crest. Alternatively they may contain a spillway or crest which are unable to safely pass fish. Under these situations it may be necessary to physically divert fish away from the hydro unit altogether and provide passage through a diversion system. Diversion systems can be quite complex and must be designed to ensure optimal operation for all local species for the expected hydrology. Detailed knowledge of local species is needed to ensure optimal performance.

#### 5.5. Certification

A Sustainability Assessment, presently in draft, is being developed by the international hydropower association as an industry audit tool to provide a mechanism to assess sustainability of new and existing hydropower schemes. It establishes a rating system for each of the key sustainability aspects, and the audit process requires the provision of evidence to support the assessment of scheme performance. The Protocol has been developed in consultation with industry and a number of international non-government agencies. It has been tested in North America and Europe, with tests planned for Africa and Asia, to assess its applicability to schemes at a range of scales and in a range of contexts.

Development of a Sustainable Hydropower Certification Program for the Lower Mekong Basin would demonstrate that a project meets a certain standard of sustainability performance. Schemes would undergo an assessment rating under the Sustainability Assessment and obtain verification of their achievements through certification. Assessments would be undertaken as formal audits by auditors accredited with a certification governing board. Such a program would provide assurance to potential owners, investors, developers, regulators, insurance providers and other stakeholders about minimisation of risks. The IHA further suggests following a consistent protocol for hydropower development (IHA 2004). These stages should be applied to all hydropower projects, be they small or large, and governments should develop the appropriate mechanisms and tools to ensure each step is adequately scrutinised and implemented.

The stages for the IHA protocol include (IHA 2004) (Table 5.1):

**Initial Screening** to establish the types and scale of project risk and opportunity, and ensure consistency with environmental and other relevant policies.

**Scoping** to determine the type, level and guidelines for environmental assessment based on regulatory requirements and community input. The guidelines should define key project level environmental issues to be addressed. These in turn should be relevant to the project and appropriate to the scale and type of risk involved.

**Conduct Environmental Studies** to address the key issues outlined in the guidelines supplied by regulatory agencies, and to present the decision making authority with the relevant environmental information covering project, construction, commissioning and management.

**Appraisal** for the decision-making authority to consider the quality of information supplied by the proponent and determines conditions of development approval/license

**Implementation (construction, commissioning and operation)** to manage environmental issues during construction and operation in accordance with agreed conditions.

**Monitoring** to measure predicted impacts and the effectiveness of mitigation measures through adherence to commitments in specified management plans, licence conditions, and voluntary agreements.

Adopting and implementing a similar protocol for the Lower Mekong Basin would ensure transparency among different projects. By demonstrating that each project has met an agreed standard for implementation would provide sufficient grounds to be accepted for certification by the IHA and similar implementing agreements (IHA 2004). Standard procedures would also ensure all projects are meeting an agreed standard and demonstrate the sustainability of future projects at a catchment scale. The obvious benefit of this approach is a situation that would permit power generation, irrigation development and maintenance of fisheries production thus protecting livelihoods and local economies.

**Table 5.1. IHA Hydropower sustainability guidelines (IHA 2004)**

<b>Key Criteria</b>	<b>Explanation</b>
<i>Prioritise upgrading of existing facilities.</i>	Although hydro-electricity is an essentially efficient form of electricity generation, refurbishment and modification of operational regimes, particularly of older power stations, can often result in significant additional energy generation.
<i>Prioritise alternatives that have multiple-use benefits.</i>	Hydro-electric projects normally have a variety of other uses and benefits. These can include irrigation, water supply, fishing, flood mitigation, water-based transport, tourism and recreation. The value of these additional benefits should be considered when comparing project alternatives. The value should be discounted against any loss of benefits (including environmental costs) associated with the project.
<i>Prioritise alternatives on already developed river basins.</i>	The potential of sites on already developed rivers is not always fully realised. While consideration of cumulative and other environmental impacts is necessary it is often preferable to develop new hydro-electric projects on already regulated river systems.
<i>Prioritise alternatives that minimise the area flooded per unit of energy (GWh) produced.</i>	Increasing the area flooded generally increases environmental impacts. Impact avoidance is more effective than mitigation so the selected site and project design should tend towards minimising the flooded area per unit of energy produced (square kilometres per gigawatt hour)
<i>Prioritise alternatives that maximise opportunities for, and do not pose significant unsolvable threats to, vulnerable social groups.</i>	Where vulnerable social groups will be affected, projects should include comprehensive social and cultural enhancement programs. Projects that represent significant threats to vulnerable social groups should be avoided if the threats cannot be mitigated.
<i>Prioritise alternatives that enhance public health and / or minimise public health risks.</i>	Hydropower developments can often provide significant new public health benefits to previously poorly developed areas. Projects can also pose risks, such as increases in waterborne diseases and a temporary rise of mercury levels in fish. Where these risks exist, they need to be managed and monitored with an appropriate public health plan.
<i>Prioritise alternatives that minimise population displacement.</i>	Where population displacement is necessary, comprehensive resettlement and rehabilitation plans need to be developed and implemented in consultation with the affected population. Opportunities to modify scheme design to reduce population displacement need to be carefully examined. An example could be lowering the full supply level of a proposed reservoir.
<i>Prioritise alternatives that avoid exceptional natural and human heritage sites.</i>	Developers should make every effort to avoid, or reduce to minimum, alterations to sites of exceptional national and international value.
<i>Prioritise alternatives that have lower impacts on rare, vulnerable or threatened species, maximise habitat restoration and protect high quality habitats.</i>	Potential impacts on rare, vulnerable or threatened species should be carefully assessed as part of the decision-making process. Consideration of the creation of alternative habitats or the protection of adjacent areas should be considered as part of any mitigation program. Habitats are of varying quality, and priority should be given to protecting or restoring higher quality habitats. Significant damage to areas of high conservation value (including critical habitat for endangered species) should be avoided when adequate mitigation or compensation is not feasible.
<i>Prioritise alternatives that can achieve or complement community-supported objectives in downstream areas.</i>	Regulation of a river, or its diversion, creates environmental change in the downstream reaches. Environmental flow regimes should be developed on the basis of community-supported objectives.
<i>Prioritise alternatives that have associated catchment management benefits and lower sedimentation and erosion risks.</i>	Sites and options should be assessed for sedimentation and erosion risks, both within the reservoir and downstream. Developers need to assess the need for the creation of catchment reserves or other management strategies to reduce erosion and sediment transport. Where appropriate, support should be given for conservation areas in catchments. Construction programs should be geared to ensuring minimum disturbance and appropriate rehabilitation of disturbed sites.

## 5.6. Site assessment

To maintain consistence with international guidelines, every potential hydro site, irrespective of height and generating capacity should be subjected to a site assessment. The site assessment can be as simple as a checklist but should be sufficiently populated to enable rapid assessment of construction and conservation issues at the site. It should cover construction aspects including weir design, conservation issue physio-chemical issues, fisheries impacts and navigation concerns.

### 5.6.1. Weir/Dam design

Weir design is a critical aspect of hydropower construction. It is the weir or dam that will create the migration barrier and will require some degree of mitigation. In some instances, such as run or river schemes, there will be no need to install a structure that fully blocks the entire stream. In these instances it may be enough to demonstrate that the project will have no significant local welfare issues for fish. Key questions to consider prior to commencement of works include:

1. Is it a new structure?
2. Is it high head?
3. Will it return all water? If not, how much?
4. Will it create an impoundment?
5. Is the hydrology known and if so, will flow become depleted?
6. Does the developer have right of access?
7. Has approval from province/district/village been sought?

### 5.6.2. Conservation

As monitoring programs expand through the Lower Mekong Basin, so too should data and report repositories that enable greater access to distributional information on Lower Mekong Fish species. There has been an increase in the listing of endangered species in recent times and species of conservation significance need to be considered in the context of new and existing mini hydro schemes. There are international agreements protecting critically endangered species and any proposed scheme that places these vulnerable fauna at increased risk should be reconsidered. Specific conservation considerations are proposed mini hydro sites include:

1. Are threatened species/habitats in the area,
2. If so, what is the IUCN status
3. Are ecological survey results available? And if so, have they been used to ascertain conservation risk?
4. What is the ecology of fish species in the proposed development zone?
5. Are critical spawning sites or habitats likely to be affected?

### 5.6.3. Chemical and physio-chemical issues

Impoundments are known to accumulate sediment, heavy metals and can thermally stratify if mixing is insufficient. It is essential that mini hydro operations minimise the likelihood of poor water being discharged downstream and introducing risk to local species. These issues need to be considered early in the design process and could be determined based on experience from other similar sites, or through computational modelling.

Key questions include:

1. Is there potential for pollutants to enter the river. If so, what pollutants?
2. Are the pollutants likely to be toxic to fish?

3. Will the scheme lead to stratification?
4. Could there be salinity issues?
5. Could nutrient issues occur?

#### **5.6.4. Fisheries**

Impacts on fisheries require their own special consideration at any hydro installation. The main reason for this is that fish live in water and will be inevitably affected by any scheme which proposes to alter habitat, flows, connectivity or introduce welfare concerns. The Lower Mekong Basin is a unique system where the protection of fisheries resources will have substantial economic and social benefits. Fish are a major source of protein, calcium and hard income for many people in the Lower Mekong Basin. Maintaining fisheries productivity is essential as aquaculture or importation cannot sufficiently sustain current levels of demand. Subsequently, ensuring any planned development does not substantially impact fisheries sustainability is a critical aspect of any development proposal in order to maintain triple bottom line outcomes.

Fisheries issues need to consider:

1. Whether the scheme will significantly alter habitat?
2. Which migratory species are known from the site?
3. Are these species of particular conservation/economic/subsistence value?
4. Have the relevant DAFO officers been consulted?
5. Does the proposed scheme require a fisheries management plan?
6. Is a fishway required?
7. Is a downstream bypass or screen required?
8. Are the hydraulic tolerances of the unit within species ranges?
9. Will the scheme impact sustenance or capture fisheries?

#### **5.6.5. Navigation**

The overall impacts of proposed hydro schemes on navigation should be addressed as part of an overall impact assessment, if required. Navigation issues are more substantial at mainstem sites with large boat traffic but it is possible that access to important fisheries may be blocked by the construction of a new weir or hydro plant. It is therefore important to determine whether a scheme is likely to:

1. Impact navigation for fishing purposes?
2. Block transport routes for fish traders?
3. Substantially impact water levels to the point where navigation will be difficult?

#### **5.7. Compliance protocol**

Commissioning is a critical aspect of any design and construction process. It is essential that both biologists and engineers assess a site upon construction completion to ensure that all biological and hydraulic outcomes are achieved. This step is especially important if various assumptions were made during the design phase. For instance, if fish survey data are not available, several assumptions about species presence may be influencing operating protocols. Similarly, if design parameters were based on computer modelling techniques, it may be worthwhile determining if modelled data match actual data. The same is true for the development of mitigation measures for fish.

### 5.7.1. Post construction hydraulic verification

Hydraulic validation should include performance of the:

1. Hydro plant itself
2. Upstream fish passage facility
3. Downstream fish passage facility

#### Hydro plant

Performance of the hydro plant must occur in relation to design criteria within the constraints of expected operational protocols. Essentially the developer should be required to demonstrate that:

1. Velocities within the unit are within the expected range
2. Critical levels of shear are within acceptable criteria for fish
3. Pressure changes are within expected ranges to minimise injury and mortality
4. Blade strike probability is within acceptable limits for fish
5. There is no cavitation

#### Upstream fish passage

If an upstream fish pass has been constructed, a hydraulic assessment should be performed. Whilst it is important to assess hydraulic conditions upon completion, fishways are susceptible to fouling, deterioration and general wear and tear. It is subsequently important to ensure fishways are regularly inspected twice per year to ensure optimal operation. Maintenance reports should be kept at the relevant district fisheries office. The general process should ensure:

1. Velocities within the unit are within the expected range
2. No areas of excessive turbulence are present
3. There are no obstructions in slots/orifices
4. Headlosses are within expected ranges
5. Entrance velocities are acceptable
6. Cells are not silted
7. Walls are stable and watertight (leaking walls can lead to headloss differences especially if a large volume of water is escaping from a cell. It will increase the headloss at the upstream slot and limit fish movement).
8. Gates (if present) can be fully opened and closed
9. Automated systems (if present) work as expected

It is essential that all of the above are acceptable for the entire operating range, meaning that hydraulic assessments need to be made during both low and high flows to ensure fish passage is optimised. A fish pass will be inefficient if it only operates over a limited flow range.

#### Downstream fish passage

Before the site is assessed for successful fish movement, it is important to ensure optimal hydraulic performance. If the hydraulic conditions are outside tolerable ranges then there is little point attempting to quantify successful fish passage. If downstream fish passage has been considered, it is important that the following has been complied:

1. The expected mesh size has been applied
2. Approach and sweeping velocities are within design limits



3. There is no obvious sign of fouling (or anti fouling measures are working effectively)
4. Safe depths and velocities exist at the spillway / weir crest
5. Tailwater depths are sufficient (i.e. Fish are not impacting concrete structures)
6. Fish diversion structures (if present) are working effectively
7. Automated systems (if present) are working
8. Gates (if present) can be fully opened and closed

### **5.7.2. Post construction biological verification**

The need for biological verification will be largely determined by the consent authority. In some instances, especially where a design has been constructed for local species and previously assessed elsewhere, hydraulic verification may be all that is required to demonstrate design compliance. If the unit, however, is a new untested design or a tested design being applied in a new system with unique fauna, then biological verification will be needed to demonstrate that the unit is not having adverse impacts.

Biological verification falls into five categories:

#### **1. Turbine passage**

Some small hydro sites may require all river flow to pass through the turbine. In these instances fish passage through turbines is inevitable. Assessment of turbine passed fish generally requires an assessment of fish approaching, entering and passing through the turbine. Researchers need to ensure fish have sufficient time to depth-acclimate prior to experimentation.

#### **2. Screen and or bypass effectiveness**

Ensuring that screening facilities or fish bypass systems are adequately working and preventing all target species / life stages from entering the turbine.

#### **3. Upstream passage**

Where a fishway has been constructed it is important to determine that it is successfully providing passage for all target species.

#### **4. Spillway / Crest passage**

Fish will inevitably be entrained into any water spilled either via a spillway or weir crest. Successful fish passage via either of these mechanisms must be demonstrated following the construction of any new project.

#### **5. Reservoir and Downstream effects**

It is important, especially at sites where a new dam, weir or regulator has been constructed, to ensure that there are no significant changes to the upstream and downstream fauna following construction or during ongoing operation. Baseline monitoring of faunal changes before and after construction are the only way to quantify this risk over the long term.

### **5.7.3. Ongoing compliance reporting**

Once construction is completed, commissioning is performed, and an initial biological assessment completed, it is important to ensure that the high construction standards continue as the unit ages. Hydraulic commissioning should be repeated annually or whenever major maintenance is required (whichever is the more frequent). Biological verification should be repeated following major maintenance or if normal operation begins to create conditions that could lead to adverse impacts

such as thermal pollution, unexpected fish kills, or rapid declines in local fisher catches. Situations like these could be considered trigger points for immediate investigation. The hydropower operator should keep permanent detailed records of any assessments to demonstrate compliance with design specifications when requested.

## 6. Identification of potential sites for small hydropower generation in Vientiane Province, Lao PDR

This chapter was prepared by Andrew Jones and Rodney Vincent representing Waratah Power, an independent Power Producer offering renewable energy solutions which operates out of Sydney Australia. Please cite this chapter as:

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### 6.1. Fish friendly generation technology

Fish passage through traditional hydro turbines has proved problematic for fish in Europe, North America and Australia. There are presently plans to increase the amount of hydro generation in the Mekong catchment and there are concerns about impacts on fish. The Schneider Linear Engine (SLT, developed by Natel Pty Ltd, USA) has been developed with minimising fish fatalities as a significant aim. Rather than the turbine runner rotating in a confined space with consequent strike and shear damage the fish, the water flows between long, widely spaced horizontal blades which are attached at either end to continuous belts. The relatively low speed and the blade spacing enable fish to pass through unharmed (Figure 1)

Due to low fluid relative speeds, low blade speeds and high static pressures, the SHL can coexist peacefully with fish, specifically it accommodates the downstream passage of anadromous fish smolts. Further to their environmentally beneficial behaviour, the NATEL SLH is ideal for use in rural communities as the turbine is delivered in four components, transition, SLH cassette (containing the engine), gearbox and generator, the heaviest of which weighs only 2.8 tonne. These four components are easily assembled into the operating unit.

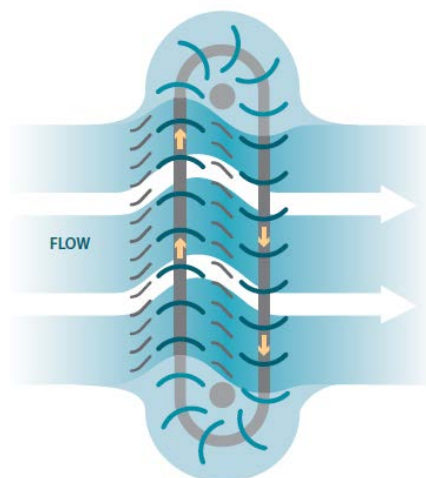


Figure 6.1. Diagrammatic explanation of flow through the NATEL SLH

## 6.2. Site inspection

In May 2013, the Waratah Power team inspected 12 potential sites for suitability for the installation of fish-friendly small hydropower units in Vientiane Province. These sites had originally been identified by the “Barriers Database Project”. Four of the sites were considered unsuitable because of too small a head or unreliable flow due to small catchment areas.

A fifth, associated with the Nam Mang 3 Power Station in Thoulakhom District, was considered very suitable by reason of the guaranteed year-round discharge from the power station (diverted from the Nam Yong River) either using the discharge over the reregulating weir or drop structures on the canal leading to the Thoulakhom Irrigation District, or both, but subsequently it was publicised that an agreement was being sought to redevelop and enlarge the irrigation area by a Chinese group (Box 6.1).

Box. 6.1. \*\*Chinese firm gets green light for irrigation study\*\*

Vientiane Times, 30 Sept 2013

The Chinese Guangdong No. 3 Water Conservancy and Hydroelectric Engineering Board Company has received approval from the Lao government to carry out a feasibility study of the Nam Mang-Tanpiew Irrigation Project.

A memorandum of understanding on the study of the proposed project in Vientiane province's Thoulakhom district was signed between the company and the Lao government at the provincial office on Friday.

Director General of the Ministry of Agriculture and Forestry's Department of Irrigation, Mr Maykong Phonphommavong, on behalf of the government, and company Managing Director Mr Chou Zhingang signed the MOU.

Under the MOU, the Chinese company will spend 18 months defining the benefits of the project, its environmental impacts, and other aspects. These must be reported to the department and provincial authorities before construction can begin.

The project aims to improve farming in the area by supplying water to about 5,300 hectares of crops in both the wet and dry seasons.

The scheme is included in the government's Seventh National Socio-Economic Development Plan, which designates Thoulakhom district as a rice supplier for Vientiane.

“The irrigation scheme will use water sourced from the Nam Mang 3 dam. We are confident there will be enough water to supply 5,300 hectares of crops,” □ Mr Maykong said at the signing ceremony.

Acting Director of Vientiane province's irrigation division, Mr Thongphoun Phanthavong, told provincial media that if the feasibility study yields positive results, the old irrigation station in the lower part of the district will be removed, and water channels will be built in its place.

Water will also be distributed through natural channels - small rivers and tributaries of the Nam Ngum.

Mr Thongphoun said the proposed project will include the installation of water gates at the mouth of the Nam Ngum's tributaries, to regulate water flow.

A reservoir will also be built if it is shown it could help to lower farming costs, Mr Thongphoun added.

Vientiane provincial Governor Mr Mhammeung Phongthady and Minister of Agriculture and Forestry Mr Vilayvanh Phomkhe witnessed the signing ceremony.

Three existing storage dams, as opposed to irrigation diversion weirs, all have considerable potential. In Naxaythong District, Nam Houm and Nam Souang Dams are medium height earthfill structures and the irrigation discharge facilities on both could readily be adapted to install generation units. Further, the Nam Houm main irrigation canal has a drop structure (Figure 2) in the main irrigation channel, 3.4 km downstream of the embankment, which could also generate energy. However, the economics of these developments will depend on the duration and volume of irrigation releases. Certainly, at the time of the inspection (given that it was at the end of the dry season) both reservoirs were empty and there was no discharge down the canals. We were unable to ascertain daily or monthly discharges from these reservoirs to assess the economic feasibility.



**Figure 6.2. Drop structure on the Nam Houm irrigation channel**

Nam Song Dam was built to divert water from the Nam Song into Nam Ngum 1 reservoir. The flow down the diversion channel has been harnessed to provide 6 MW of power. There are two further structures downstream of the power station where generation would be possible, but only when the level of the Nam Ngum 1 reservoir is close to its Minimum Operation Level. The reservoir level has been low for some years, but there is agitation from the irrigators that water is being released for power generation during the non-irrigation season keeping the level low and there is not sufficient water available when it is needed for irrigation.

At the Nam Song Dam there is a mandated release of 6 m<sup>3</sup>/sec to maintain the river environment downstream. This can rise to 12 m<sup>3</sup>/sec in high flow periods when the reservoir is full. This flow could be used to generate about 500 kW of power.

There are two promising sites in Kasi District on existing weirs.

- On Nam Kay, near the village of Ban Phonesavanh, 7 km north of Ban Viengkeo, a substantial weir about 3.5 m high diverts water to a small irrigation area (Figure 6.3). There is no information available on flows or diversions, but there is a substantial catchment area of 158 km<sup>2</sup> in hilly terrain. There was flow past the weir when we inspected, although no irrigation diversion. There was evidence of aquatic life as there were fixed nets set to catch upstream moving fish.



**Figure 6.3. Nam Kay weir**

- Near the villages of Ban Naxou and Ban Phongnam, 3 km north of Ban Viengkeo on Highway 13 N, there is a 4 m high weir on Nam Khut (Figure 6.4). This has a catchment area of 450 km<sup>2</sup> and there was a reasonable flow at our inspection, however, there is no available data on year round flows.



**Figure 6.4. Nam Khut Weir**

Both these sites are within several hundred metres of existing 11 kV distribution lines and also villages that would use energy generated from the streams.

There are two sites in Vangvieng District, near the village of Ban Phonesavang, 11 km south of Ban Vangvieng on Highway 13 N.

- Nam Mon has a small catchment area (45 km<sup>2</sup>), but has a drop into the irrigation canal.



**Figure 6.5. Nam Mon Weir**

- Ban Nalao weir is on Nam Ghat about 5 km east of Highway 13 N. It also has only a small catchment (20 km<sup>2</sup>) (Figure 6.6).



**Figure 6.6. Ban Nalao Weir**

There is no data on streamflows at either weir, but the small catchment area casts some doubt as to the feasibility of retrofitting generation units at these sites.

## 6.3. Possible site development.

### 6.3.1 Nam Mang 3<sup>a</sup>

There are two discharges from the reregulating dam – over the weir and down the Nam Gnyam and through the irrigation diversion channel to the Thoulakhom Irrigation District's main channel at Ban Nam Nyam.

The reregulating weir is an uncontrolled discharge over a 76 m wide ogee crest with a design discharge of 22 m<sup>3</sup>/sec. The reservoir has an operating range of 2.5 m between MOL and FSL. The weir is 9.6 m high and it would be possible to construct a channel or pipeline around either abutment leading to a powerhouse about 50 m downstream to harness a head range of 7.5 to 10 m (Figure 6.7). A discharge of 5 m<sup>3</sup>/sec would generate about 400 kW at FSL.

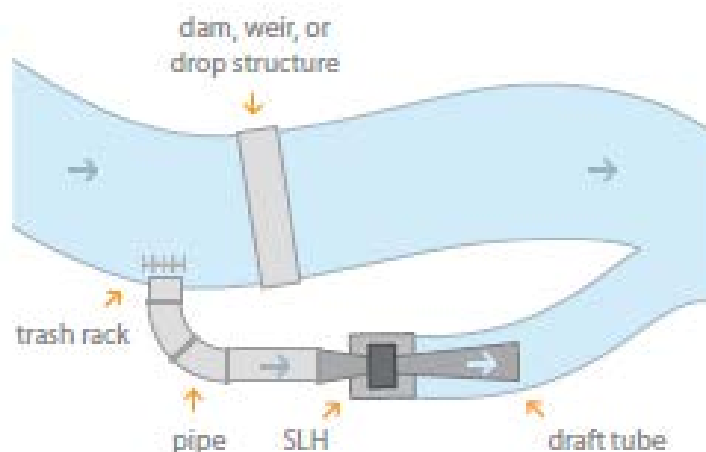


Figure 6.7 – Schematic layout of arrangement around weir

The irrigation diversion channel is 1.846 km long with a maximum design flow of 4.8 m<sup>3</sup>/sec. There are two drop structures, one immediately above the end of the channel at Ban Nam Nyam (Figure 6.8), but the total drop between the reservoir and Ban Nam Nyam is not known. Each drop structure could be bypassed to construct a small generating unit, 100 to 200 kW, sufficient to provide energy to Ban Nam Nyam and the surrounding villages during the irrigation season (Figure 6.9). When the irrigation channel is not in use, energy would be generated at the reregulation weir.

It is not possible to assess the size and economics of installations at Nam Mang 3 because of lack of data regarding:

- Details of the irrigation channel and drop structures
- Actual flow through the power station
- Historical flows over weir and down irrigation channel.

<sup>a</sup> Nam Mang 3 Hydropower Development Project. Electricite du Laos Generation Public Company





Figure 6.8 – Drop structure at Ban Nam Nyam

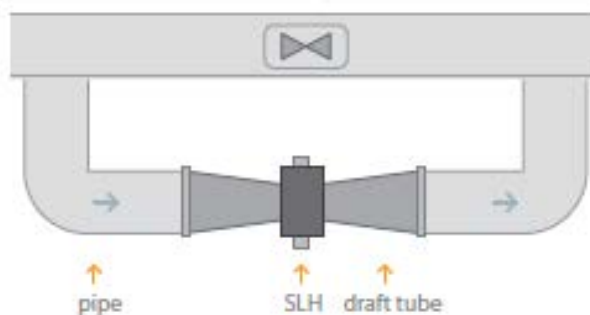


Figure 6.9. Typical arrangement around drop structure

### 6.3.2 Nam Houm

Nam Houm is an irrigation storage on a tributary of Nam Ngum in Naxaythong District of Vientiane Province (Figure 6.10, Figure 6.11). While a generation unit could be placed at the outlet from the dam the more attractive site is a drop structure on the main irrigation canal about 5.3 km downstream of the embankment. Here the drop is approximately 6 m and for a 4 m<sup>3</sup>/sec flow (the outlet works capacity at MOL)<sup>b</sup> approximately 200 kW could be generated in a similar arrangement (See Figure 6.9). Maximum discharge is a lot larger as there is 8 m between MOL and FSL



Figure 6.10. Entrance to drop structure



Figure 6.11 - Drop structure from downstream

<sup>b</sup> Construction of Irrigation System for Nam Houm Dam in Vientiane Plain. Interim Committee for Co-ordination of Investigations of the Lower Mekong Basin, December 1986

To prove the economic feasibility the following information is required:

- Drawing of the drop structure and adjacent channel
- History of discharges down this channel, preferably daily, but monthly would suffice. It is doubtful that actual figures exist, but some assessment could be made by the relative size and water demand (whether there are crops, fish farms, animal breeding etc) of developments upstream and downstream of the structure

### 6.3.3. Nam Souang Dam

Nam Souang is an irrigation storage on a tributary of Nam Ngum in Naxaythong District of Vientiane Province<sup>c</sup> (Figure 6.12). Immediately downstream of the embankment, the outlet works discharge into a channel, controlled by a gated structure 110 m from the toe of the embankment. A further 40 m downstream a drop structure is the commencement of the main irrigation channel.

The proposal is to construct a pipeline from the outlet to downstream of the drop structure (Figure 6.12) to mobilise the head during irrigation season. There was little flow at the time of our inspection just prior to the commencement of the rainy season. To prove the economic feasibility the following information is required:

- Drawing of the outlet structure (pipe sizes, levels etc)
- History of reservoir levels and discharges, preferably daily, but monthly would suffice.



Figure 6.12. Proposed layout for development at Nam Souang

<sup>c</sup> An Inventory of Wetlands of the Lao P.D.R.. Gordon Claridge 1996 pp 85-88

### 6.3.4 Nam Khut 1

This 4 m high weir is in Kasi District, adjacent to Highway 13 N (Figure 6.13). It presently provides irrigation water to a small cropped area. Generation could be implemented by a diversion around the weir (See Figure 6.7). There are no available flow measurements for this stream, but EdL Generation has constructed a 14 MW hydro station on Nam Sana, about 4 km east of the Nam Khut weir. It may be possible to transpose the flows that were used in the Nam Sana feasibility study, adjusted for different catchment areas, to the other sites in Muang Kasi.

The Nam Sana Project Design Document as quoted in the CDM application<sup>d</sup> quotes a catchment area of 96 km<sup>2</sup> and a “reservoir inflow” (presumably the long term average flow) of 5.96 m<sup>3</sup>/sec. There is no mention of seasonal variation, but the scheme is run-of-river with no storage capacity in the diversion weir, which is 7 m high, but the turbines are sized for a design flow of 11.5 m<sup>3</sup>/sec.

For a 14 MW installation, the expected energy generation is 49.55 GWh/annum, which equates to a capacity factor of about 40%

Nam Khut has a catchment area of 450 km<sup>2</sup> so an average discharge of about 25m<sup>3</sup>/sec could be assumed, enough to generate 800 to 900 kW. These figures are only averages and to fully propose an arrangement and carry out an economic analysis, detailed drawings of the weir and more precise estimates of flow, including seasonal variation and the likely irrigation requirements.



Figure 6.13. Nam Khut 1 Weir, near Ban Muang

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<sup>d</sup> <http://cdm.unfccc.int/Projects/Validation/DB/A0DW9MCVAID7IP64NX8B2V2R0OGXW3/view.html>

### 6.3.5 Nam Kay

Also in Kasi District, this weir irrigates 252 ha from a catchment area of 158 km<sup>2</sup> (Figure 6.14). We have not been provided with any flow data, but using the same approach as at Nam Khut 1 comparing with the basic Nam Sana information, an average flow of about 6 m<sup>3</sup>/sec can be estimated.

The proposed layout would be to divert from above the weir on the left bank and discharge through a generator into the irrigation channel. A bypass would be constructed in the irrigation channel to return water to the river when not needed for irrigation.

To proceed further need detailed drawings of the weir and flows, to irrigation and past the weir.



Figure 6.14. Nam Kay Weir and sluiceway



Figure 6.15. Irrigation channel

### 6.3.6 Nam Mone

Nam Mone has only a small catchment and there was little flow at the time of our inspection. Advantage could be taken of the sluiceway on either bank or, preferably, the drop into the irrigation channel on the right bank to install a small SLE generator

Without knowing the flow information and the details of the weir, the economics of the installation could not be assessed.

### 6.3.7 Nam Nalao

The Nam Nalao weir is quite substantial, 44 m wide and 2 m high (Figure 6.16). However, there is a small catchment area and there is no data available on flow at various times of the year.

There is no irrigation channel leading from the weir and water is discharged over the weir crest or through two uncontrolled slots or through gate controlled sluiceways at either bank (Figure 6.16).

Either or both sluiceways could be modified to incorporate a pipe leading to a small generator a short distance downstream to maximise the head, with the slots in the weir crest being filled in, but economics of this option would depend on knowledge of the flow regime throughout the year.



**Figure 6.16. Sluiceway at Ban Nalao weir**

### 6.3.8 Nam Song

EdL has successfully implemented a generation unit midway along the diversion channel from the Nam Song to the Nam Ngum reservoir. Opportunities exist for a similar, albeit smaller, project at the canal water level control approximately 2.4 km downstream of the EdL station. On present arrangements of the structure, with concrete stoplogs removed, the crest level is EL 207.7.m and there is a nominal fall to a channel level of EL 201 immediately downstream. However, the downstream water level is controlled either by the backwater from the weir canal water level control(EL205) at the Highway 13 crossing 1.5 km further down the channel or the Nam Ngum reservoir level, which can be as high as EL 212 (FSL) and which would submerge the control structure. Normal draw down of the reservoir is EL200, with minimum operating level of EL196. Although there is more than adequate flow in the channel (during the 16 years since the diversion was completed, the monthly average flow down the channel has varied from 7.6 m<sup>3</sup>/sec in March to 151 m<sup>3</sup>/sec in July) the unreliable nature of the available head would make any installation here an economic risk.

The better development option for Nam Song would be to take advantage of the mandatory releases down the river from the weir. There is a slot in the spillway crest adjacent to the left abutment, 4.5 m wide by 1 m deep. At FSL the mandated discharge is 12 m<sup>3</sup>/sec, but with the reservoir maintained 0.3 m below the spillway crest the discharge is only 6 m<sup>3</sup>/sec . There is no other facility to release water from the Nam Song reservoir.

A pipe could be located in the backfill adjacent to either abutment (Figures 6.17 and 6.18) show it on the right bank, but could equally be on the left) leading to a generation unit at the end of the spillway side wall.

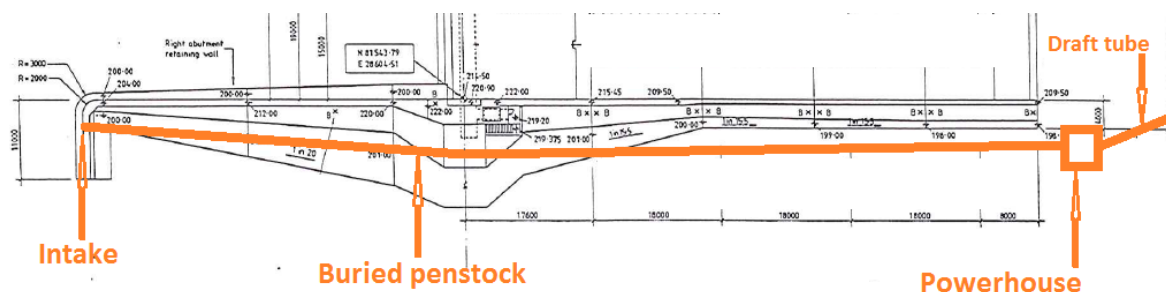


Figure 6.17. Plan of suggested arrangement at right abutment of Nam Song Dam

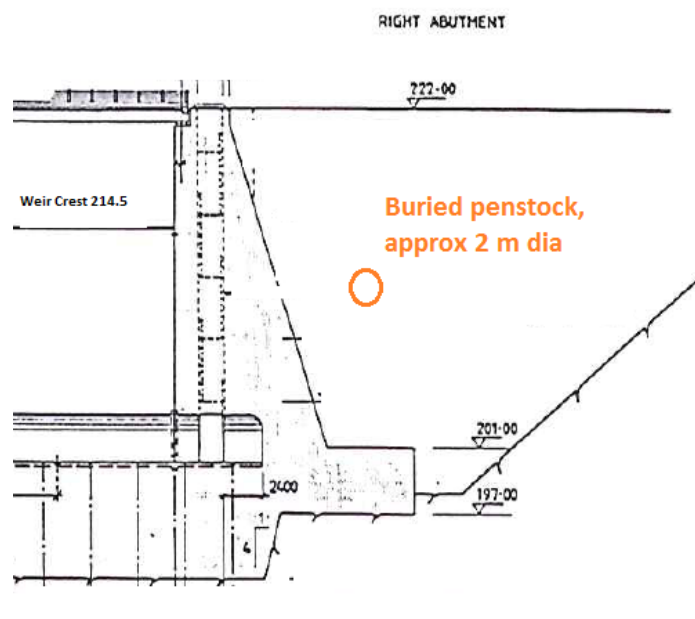


Figure 6.18- Section through right abutment of Nam Song weir, showing suggested arrangement

The available head is approximately 15 m with only the mandatory release. It would be less when the inflow into the reservoir exceeds 210 m<sup>3</sup>/sec, the capacity of the diversion channel. The potential generation capacity would be approximately 1.5 MW when passing the 12 m<sup>3</sup>/sec environmental flow.

Potential annual energy output could be estimated if the daily records of inflow to the reservoir and outflow to the diversion channel were available, together with backwater curves for flow downstream of the weir.

#### 6.4. Summary

As noted above, the available data, streamflow, irrigation demands, structure information was not available. Nevertheless, an effort has been made to identify possible generation developments on a number of locations. However, before any of these can be progressed further to feasibility level this data will have to be made available. At every site considered, there is an existing EdL 22 kV distribution feeder passing close by the site so that evacuation of the energy could be achieved with little expense regarding cost of transmission lines.

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## **Appendix 1. Report on sustainable hydropower and irrigation infrastructure workshop, Lao PDR, Vientiane**

### **A.1. Introduction**

It is estimated that there are thousands of water retaining, control or diversion structures in the Lower Mekong Basin. River structures have varying levels of impact on the natural environment, including impeding upstream fish migration and causing high mortality rates during downstream migration.

With the increasing emphasis on both developing new sources of renewable energy and providing economic development opportunities in rural areas, there is significant potential for sustainable development of small-scale and mini-hydro schemes on some of these structures, particularly in rural regions. An additional benefit would be improved downstream fish passage (beyond existing weir or gated structures) through hydro schemes which have been developed using “fish-friendly” approaches and technologies.

Many countries have identified the potential to develop renewable energy through small-scale hydro plants installed on existing “non-powered” water retaining structures. The development of small hydro equipment claiming “fish friendly” attributes is also increasing. However, there had been little previous assessment and study to investigate this opportunity from a holistic perspective, taking into account the opportunity, technology, biology (fish migration), implementation, financing and regulatory aspects as they relate to small scale and mini-hydro.

There is still concern among some regulatory and consent agencies that mini hydro solutions may impact fish populations. However, in recent times there has been a substantial body of evidence collected on non-salmonid species which could help to advance application of this technology.

This workshop was targeted towards developers, regulatory agencies and water managers with a view to increasing the knowledge about both the science and technology for wider application. The proposed agenda will include experts covering the full range of topics with invited international participants (Table A1). The outcome will be an improved understanding of the potential impacts of small hydro plants on fish and an agreed way to proceed with hydropower design and installation.

### **A.2. Speaker Summaries**

#### **The speech of NAFRI Deputy Director to the Mini-Hydro Development Workshop Mr Soulivantong Kingkeo**

You're Excellency's. Participants, Lady and Gentlemen,

On behalf of NAFRI Director and Chair of the Workshop I would like to welcome you to this very important workshop. Freshwater fish comprise 41% of fish species worldwide but now are in rapid decline. The Lower Mekong Basin freshwater fish, in particular, are a very important protein source (e.g. 48% of total protein consumption in Lao PDR) and the total yield of the capture fishery represents 2% of the entire global catch. The total fishery yield, however, has declined substantially over the past 50 years. Enhancements to fishing technology, increases in food demand and infrastructure development such as river regulation and extractive water use threaten riverine ecosystems and will lead to further declines if appropriate mitigation measures are not investigated.

**Table A1. Agenda of the first national workshop on mini hydro development, Lao PDR, Dongdok Campus, National University of Laos, August 2013**

Time	Item	Officer
8.30	Registrations and Coffee	
9.00	Workshop preliminaries and Welcoming Address	Chairperson
9.15	<b>Session 1. Issues concerning downstream migration of Lower Mekong fish species</b>	
9:15	Presentation: The need for specific fish research in the Lower Mekong Basin	Mr Douangkham Singhanouvong, LARREC
9.45	Presentation: Determining the effects of fluid shear on fish – the flume experiments	Mr Garry Thorncraft, National University of Laos
10.15	Morning Tea and group photo	
10.45	Presentation: Survival of Mekong fish during passage through irrigation infrastructure – simulation experiments	Dr Oudom Phonekhangpeng, National University of Laos
11.15	Presentation: Physiology of Mekong species and tolerances to different hydrological criteria – the Barokeg and Barotrauma Experiments	Dr Craig Boys, Fisheries NSW
11.45	Presentation: Incorporating biology into design of irrigation infrastructure – Case study from Australia	Dr Lee Baumgartner, Fisheries NSW
12.00	Group Discussion	

Many factors contributing to these declines can be mitigated, but require mitigation measures to be based on robust scientific methods that are complemented by efficient management strategies specific to Lower Mekong species. We cannot rely on criteria developed elsewhere, for other species, to be applied in our region where our fish have very unique biological requirements.

The main objective of this workshop is to discuss fish passage downstream through small dams/weirs. Specifically, we would like to explore the development of mini hydro technology which has the potential to provide income and power generation for villages and districts on a local scale.

However, it is important that the development of new technology has no impacts on fish, because these are extremely important in the Lower Mekong Basin. Today we will exchange ideas and knowledge on how to develop mini hydro plants to enable fish to pass through safely. The main aim of the workshop is to develop ideas that will allow power generation, but also maintain existing fish populations and rice production. We will hear from various speakers who will highlight the risks associated with fish passage through mini hydro plants, but then also hear about how we can perform research to help minimise these risks. Today we would like to generate open discussion on the approaches we propose and gain endorsement from the participants in order to development and



improve our full project proposal in the future. Together with your feedback we hope to develop a multi-country project involving experts from Lao PDR, Australia and United States of America with joint funding from a number of sources.

Given the level of interest in hydro development in Lao at the present time we think the idea of new project to develop solutions, rather than just outline a problem, will be beneficial. In the long term we hope this will minimise an impact of weir/small dam development in Lao PDR as well as in the Lower Mekong Basin in the future. We fully support this idea and hope to make our dream be come true of having sustainable fish populations.

Finally, on behalf of NAFRI and myself I would like to wish this workshop to succeed and wish you all happy and good luck for New Year. May I declare workshop to be open from now on.

Thank you

### **The need for specific fish research in the Lower Mekong Basin**

#### **Mr Dounagkham Singhanouvong**

All Mekong fish species need to move upstream and downstream. Previously most work has focussed on upstream movements; in particular guiding the construction of fishways. Many fish also have a specific need to move downstream. For instance, whilst many fish may migrate upstream to spawning grounds, eggs and larvae must then drift downstream. Some fish will migrate downstream to refuge habitat during the dry season. In addition, fish which perform important lateral movements into floodplain wetland habitat for spawning and nursery habitat. These fish, eggs and larvae must then move downstream to return to the main channel when water levels recede. There are many proposals to construct small hydro plants and regulators in areas where fish move downstream. It is important that any structure is designed to allow downstream fish movements to occur. We proposed to conduct a series of experiments to determine the critical causes of fish welfare issues when downstream migrations are performed. If we can determine the overall risks associated with hydro plant passage then we can ensure that developers are able to include fish friendly criteria into the design process and ensure sustainability of the project.

### **Determining the effects of fluid shear on fish – the flume experiments**

#### **Mr Garry Thorncraft**

Research, using innovative technology that can provide pressure and velocity information was performed to identify the effects of turbine passage on fish. The unit, called a sensorfish, can record 2000 data recordings in one minute. Performed laboratory trials initially, then validated with field trials, to understand the overall changes experienced by fish. A flume was constructed where shear forces can be manipulated in a hydraulically controlled environment. Silver shark (*Balantiocheilos melanopterus*) were released into the tank, under known shear and velocity conditions, and any impacts or injuries are observed. Exposure to high velocity jet can cause eye exophthalmia and also damage to gills and opercular hood. When velocity is less than 12 m/s, fish survival is good. However, when over 15.2 m/s, mortality rate is then over 60% of fish exposed to the hydraulic conditions. It was important to note that results different than those obtained for North American species. These further suggest that scientific experiments must be carried out on Mekong species to help inform hydro plant design in the region. Designs that favour low degrees of fluid shear and reduced turbulence would have huge advantages over other designs and should be scoped for application.

### **Survival of Mekong fish during passage through irrigation infrastructure – simulation experiments**

**Dr Craig Boys**

Small scale hydro is an emerging industry worldwide. There are many fish friendly options available and opportunities to install new facilities are emerging frequently. Most previous research on fish passage through hydro plants has been based on North American salmon but the research approaches could be applied to fish of the Lower Mekong Basin to inform design of both mini hydro facilities and construction of weirs. The passage of fish through undershot and overshot weirs was discussed and it was determined that undershot weir design can cause very high mortality in some species of fish. The main hydraulic conditions fish experience during passage through an undershot weir is similar to passage through a hydroelectric turbine. All fish experience a pressure change, fluid shear and turbulence. The pressure change of an undershot weir can be extremely high, and in some instances the rate of change is worse than passage through a hydroelectric turbine. We performed research to determine whether irrigation infrastructure could be improved to maximise fish passage success. We found that passage through an undershot sluice gate was particularly damaging for Mekong species and that fish passing through an overshot weir were largely unharmed. These results could be applied to new regulator designs in the Lower Mekong Basin to improve fish sustainability.

### **Physiology of Mekong species and tolerances to different hydrological criteria – the Barokeg and Barotrauma Experiments**

**Dr Oudom Phonekhampong**

Fish can pass a hydro facility in one of three ways. Firstly, via the spillway, secondly, via a fish bypass system and finally through the turbine itself. For some fish, the only passage route possible is through the hydro turbine. Fish experience injury from 3 sources when they pass through turbine:

Physical strike

Shear forces

Injury from pressure changes

Not all fish experience all three of these injury sources, but all fish that pass through a turbine will experience a change in pressure. Fish move through the turbine, pass into a draft tube and then into the tailrace. A fish moving down this passage route will experience a compression, then decompression, then recompression. This influences the swim bladder of a fish. The swim bladder doubles in size each time the external pressure is halved (Boyles Law). A fish passing through a hydro turbine will have the swim bladder compressed, then expand, then compress again. If the turbine expands too far, then the swim bladder may explode. Many injuries seen are fish with bubbles in the eye, fins and gills. If bubbles are in the gills, fish may die from suffocation. Also see fish with eye exophthalmia but most common is swim bladder rupture. X-rays showed that, when the swim bladder ruptures, expressed air can damage muscle tissue. Simulations of hydro turbines determined that different species will have different responses to pressure changes. This depends on the swim bladder design and varies between Mekong species and salmonids, for which most of the existing data is available. The main discussion point was that if fish need to pass through hydro power systems, and then need to mitigate impacts to ensure fish injuries are not leading to overall population declines. Focusing on hydro power options with low pressure differentials was seen as something that would be beneficial for fish.

### **Incorporating biology into design of irrigation infrastructure – Case study from Australia**

**Dr Lee Baumgartner**

Previous research demonstrated that different types of weir infrastructure can be damaging to fish. Experiments carried out in Australia determined that passage through undershot weirs, where water is discharged below a sluice gate, can be extremely damaging to native fish larvae. By comparison, passage over a fixed crest overshot weir passed the majority of fish safely. Examination of data could not determine whether fish were damaged by fluid shear, pressure changes or physical strike. Data did demonstrate that there was some aspect of overshot weir passage that provided safe conditions for fish. Further research determined that the depth of the downstream plunge pool substantially influenced survival. Fish landing in deeper water experienced much greater survival. These results were used to construct fish friendly infrastructure. A number of regulator upgrades and new weirs were constructed using new designs. Instead of applying undershot sluice gates, forward tilting lay-flat gates were installed. Downstream of each gate was a deep plunge pool which prevents fish from contacting the downstream apron. Twenty three of these new structures have now been installed and another twenty are planned as part of weir upgrade works throughout the Murray-Darling Basin. The works are a direct example of how fish passage results can be applied to engineering projects to bring about positive outcomes for fish without compromising irrigator requirements.

**Closing Remarks, Mr Soulivanthong, Deputy Director General NAFRI**

The workshop today on downstream migration was an excellent opportunity to share experiences about advances in fish passage in Lao PDR and Lower Mekong Basin. The energy ministry and irrigation department are thanked for helping to learn about the present issues and try to help come up with sustainable solutions for fish. Electricity, water and fish are very important in Lao PDR. These are essential to have long term benefits for Lao people. It is excellent to see new information and cooperation among all government departments to ensure sustainable outcomes for the Lao people. The Lao government is very interested to see collaborative research performed that will have practical benefits to Lao. Any concept for a new project would be supported from Lao authorities. Great thanks are expressed to presenters, thank you for your participation; I wish you good health and safe travels. There were no further comments so chairman declared the meeting closed at 12pm.

**A.3. Workshop outcomes**

The workshop was extremely productive. Speaker presentations were well received and participants were impressed by the fact that there are practical solutions available to help mitigate the impacts of hydro development on fish. The main message discussed during panel sessions was to learn from other countries that have implemented hydropower projects and had disastrous ecological outcomes. By not considering fish during the construction phase, the need for mitigation techniques was not realised until populations began to decline. Mitigation options then needed to be retrofitted to existing structures which was very expensive and has large ongoing monitoring programs. The group collectively agreed that implementing sustainable practices from the outset was a more practical and progressive activity. The National University of Laos also showcased newly acquired barotrauma chambers using small-bodied fish obtained from local aquariums. Research staff demonstrated simulated turbine conditions to highlight potential impacts on fish. The group hoped that future research will lead to specific hydro designs for the Lower Mekong Basin.

**A.4. Workshop participants**

Name	Position	Organisation
Mr. Lieng Khamvilay	Director	LARReC

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

<b>Name</b>	<b>Position</b>	<b>Organisation</b>
Dr Sinthavong Viravong	Deputy Director	LARReC
Mr Douangkham Singhanouvong	Deputy Director	LARReC
Mr Somphannit Senesitane	Chief of Planning Section	LARReC
Mrs. Khampheng Homsombath	Chief of Capture Fisheries Section	LARReC
Mr. Bounsong Vongvichith	Chief of Aquaculture Research Section	LARReC
Mr. Ounkham Khammounsoth	Chief of Nongteng Research Station	LARReC
Miss Kate Martin	Volunteer	LARReC
Mr. Garry Thorncraft	Research Associate	NUOL
Mr Lotsami Soulivongsa	Teacher	NUOL
Dr. Oudom Phonkhampheng	Dean	NUOL
Mr. Thonglom Phommavong	Teacher	NUOL
Dr. Phouvin Phousavanh	FoA	NUOL
Ms Malavanh Chitavong	Teacher	NUOL
Mr Phousone Uolasaan	Technical	NUOL
Mr. Kingkeo Saikhambay	Research officer	NUOL
Mr Chaineuk	Director	Bolikhamxay Province
Mr Somvang Keovongvichit	Director of Agriculture	Pakxan District
Ms Vanpheng Saysongkham	Director of Cabinet	Pakxan District
Mr. Viengsavann	Head of Agriculture Cabinet	Pakxan
Mr. Anousay	Staff	Pakxan District
Mr. Vone	Villager	Pakxan District
Mr. Somano Phounsavath	Acting Division Director	Livestock and Fisheries
Ms Phanmali Sengdaldasack	Deputy Director	Champhone District
Mr Somsouk Phanthavong	Director of Technical Unit	Sayphouthong District, Savanakheth
Mr Khamchan Sidavong	Deputy Director	Livestock and Fisheries, Savanakheth
Mr Bounma Theapphousai	Director of Cabinet	Sayphouthong District, Savanakheth
Mr Phansy	Director of Fishies Unit	Savanakheth Province
Mr Vanpheng Sengmanothong	Head of Division	Planning and Cooperation
Mr Khammoun Akasai	Technical Teacher	Water Resources College
Mr Sarkone Saynyasone	Technical	Department of Water Resources
Ms Ngunmani Khamphoumi	Technical	Environmental Research Institute
Mr. Sousakhone	Technical	Dept of Environmental Health
Mr. Souphon Chanthalangse	Technician	Environmental Impact Assessment
Mr. Phouthaseng Singphaseuth	Officer	Dept of planning, MAF
Mr. Khamchai Phothideth	Head division	Planning and Cooperation
Mr. Bounman Keomorkod	Officer	Research Management Division
Mr. Xayyadeth Norlasing	Officer	Planning division, NAFRI
Mr Vinaithong Nargkavong	Technical	NAFRI
Mr. Soulivanthong Kingkeo	Deputy Director	NAFRI
Mis Maniphanh Sainorlath	Officer	Dept Irrigation
Dr. Daovong Phonekeo	Director	Energy Policy and Planning
Mr Vilaphon Vinsounnalart	Director of Environment Office	EDL

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

<b>Name</b>	<b>Position</b>	<b>Organisation</b>
Dr. So Nam	Programme Coordinator	Fisheries Programme, MRC
Mr. Voradeth	Coordinator	ISH MRC
Mr Chanthaphon Thammavong	Director	WWF - Comfish
Dr Chris Barlow	Research Program Manager	ACIAR
Dr. Lee Baumgartner	Senior Research scientist	NSW DPI
Mr. Victor Cowling	Manager	WWF
Dr. Boonsong Srichroendham	Director Fisheries Unit	DoF Thailand (BKK)
Ms.Renu Sirimongkonthaworn	Head Udon Fisheries Station	DoF Thailand (Udon)
Ms.Tiwarat Thalerngkietleela	Officer Udon Fisheries Station	DoF Thailand (Udon)
Ms. Siranee Ngoichansri	Officer	DoF Thailand (Udon)
Ms. Paweena Phiwkham	Officer	DoF Thailand (Udon)
Dr. Richard S. Brown	Senior Researcher	USA
Dr. Daniel Deng	Senior Researcher	USA
Mr Simon Krohn	Director	MRC Sustainable Hydro
Mr Niels Nielsen	Secretary	International Energy Agency Hydro
Dr Rick Switzer	Regional Hub Chief	US State Department
Dr Craig Boys	Research Scientist	Fisheries NSW
Kenji Yokokawa	Engineer	Japan
Emmanuel Branche	Sustainability Manager	Electricite du France
Geraldine Duvochel	Sustainability Manager	Electricite du France
Mr Brett Pflugrath	PhD student	University of NSW
Mrs. Chiraporn Sunpakit	Country Manager	ACIAR, Laos
Dr. Chumnarn Pongrsii	Director	SEAFDEC