Protecting downstream migrating fish at mini hydropower and other river infrastructure

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Wayne Robinson provided biometric support and assisted in developing the experimental design outlined in Chapter 5. Michael Lowry was responsible for creating all of the informative conceptual drawings provided in this report.

NON-TECHNICAL SUMMARY

Protecting downstream migrating fish at mini hydropower and other river infrastructure

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NON TECHNICAL SUMMARY:

Society relies on a vast network of river infrastructure (including dams and weirs) to capture and regulate flows for agricultural, domestic and industrial use. These structures can also be used to produce hydropower. New South Wales has the largest hydropower capacity of any Australian State, with hydroelectricity comprising 63% of total renewable electricity generation last year. Whilst further expansion of large dam hydropower is unlikely, given the low topography and variable rainfall in Australia, there has been renewed interest in exploring the utilisation of existing weirs, and irrigation supply networks for power generation using small-scale or mini hydropower (typically <10 MW). This interest is being reflected throughout the world, where mandatory renewable energy targets set by governments and a movement away from nuclear power is encouraging investment into “low-carbon” generating sources such as hydropower.

Future river infrastructure planning (including mini hydropower) should balance economics with the risk of environmental harm to ensure the protection of migratory fish populations. The past expansion of river infrastructure and flow regulation has been implicated as a major cause of global declines in freshwater ecosystems. Dams and weirs fragment habitats and alter hydrology which can disrupt fish spawning and prevent or delay upstream and downstream migrations. These structures, as well as hydropower turbines, have also been shown to create adverse hydraulic conditions such as rapid pressure changes and turbulence which can injure or kill fish during downstream passage. The implication of increased injury and mortality can be lower recruitment and reduction in population sizes.

There is a lack of science and a significant amount of uncertainty surrounding the potential impact of using existing irrigation weirs as mini hydropower generators in Australia. Whilst new technologies are becoming available in the mini hydropower sector which may provide for safer fish passage, the tolerances of native fish at egg, larval, juvenile and adults stages to passage through mini hydropower plants remains unstudied. Given the vast numbers of fish that have been shown to migrate downstream and evidence that they can be injured as they pass through existing weir structures, research is required to better understand the potential risks associated with new mini hydropower technologies on fish populations. Without this information, it is not possible to make informed decisions regarding the relative social, economic and environmental aspects of hydropower development.

The current project sought to determine what questions need to be addressed through targeted research in order to provide developers and fisheries authorities with the confidence to make informed design and policy decisions regarding future mini hydropower and associated river infrastructure developments. The ultimate objective is to establish the research and development capacity within New South Wales to facilitate improvements in passage conditions for fish species (including threatened species) at river infrastructure and enhance the State's capacity to implement new, sustainable energy technologies in regional areas.

A workshop was convened at the start of the project which brought together representatives of fisheries management authorities, researchers and hydropower development companies to seek agreement over the gaps in knowledge that need to be addressed and to seek clarification on how research findings can be used during the approval process. Twenty-four participants from agencies in Australia, Lao PDR and the United States participated in the workshop and there was general agreement among participants on the key requirements:

1. Enhanced knowledge on the ability for native fish to safely pass through mini hydropower systems;
2. Production of a clearly-defined set of acceptable biological criteria for mini hydropower operation and construction;
3. Experimental field validation that newly-developed designs are "fish-friendly", preferably in low-risk habitat (such as an irrigation offtake regulator); and
4. Improved understanding of how research outputs would be integrated into the development assessment process.

Participants collectively agreed that a structured research and development program was needed, one which used a combination of laboratory and field-based trials. Laboratory trials would seek to identify the critical tolerances of Australian fish to pressure change, water turbulence and blade strike. These experiments would be best applied within an adaptive management framework, where information of the critical tolerances of fish could be used to develop pragmatic ways of mitigating risks, through improvements in design or operation. Given the potential for emerging mini hydropower markets throughout Australia and south-east Asia, and given the extensive body of work already underway in the U.S., it was felt that there would be significant value in continuing to foster a collaborative research effort throughout the Asia-Pacific region.

Subsequent chapters of this report outline direct field, as well as modelled, observations of hydraulic conditions at a large undershot irrigation weir in the Murrumbidgee River (Hay Weir). This work identified that fish passing through the structure would be subjected to rapid decompression that could lead to pressure related injuries (barotrauma). Along with modelled hydraulic conditions obtained for a mini hydropower unit and mortality estimates obtained from laboratory trials on North American salmonids, this information was used to design pressure chambers and experiments that will be used to simulate hydropower plant and weir passage for a number of native species and life stages, enabling injury and mortality estimates to be determined. This report also outlines the design and construction of facilities and experiments to test the critical range of shear forces (generated when water of different velocities intersect in turbulent flows) for native fish. The results of these experiments will also be able to identify tolerable ranges for future infrastructure design.

Fish welfare at river infrastructure is a global problem and investment into research and development is required if current fisheries declines throughout the world are to be addressed, whilst investment in emerging energy sectors is supported. Through the activities outlined in this report the capacity to begin undertaking this important research has been established. Safe passage of fish through hydropower needs to be considered during the construction and approval phase, not as an afterthought.

GLOSSARY OF TERMS AS DEFINED IN THIS REPORT

Barotrauma	Injury caused by rapid or extreme changes in pressure.
Computational Fluid Dynamics (CFD) modelling	The use of numerical methods and algorithms to simulate the interaction of liquids and gases with surfaces.
Head	The difference in height between the head water and tailwater at a reservoir. Head is used to store kinetic energy in water.
Hydropower	The generation of electricity from the kinetic power of moving water. The kinetic energy of water is typically generated by having two water bodies at different heights (termed head), usually at a reservoir dam or weir. In a typical installation, water flows over a turbine, generating pressure which causes the shaft to rotate. The rotating shaft is connected to an electrical generator which converts the motion of the shaft into electricity.
hydroEngine™	A type of mini hydro system manufactured by Natel Energy which operates by transferring energy from falling water impacting a series of horizontal blades to a power train that rotates around an upper and lower shaft. A generator is connected to one or both of the shafts. (http://www.natelenergy.com/products/technology.html) The hydroengine was used as a case study for comparison of baseline hydraulic conditions at an undershot weir in Chapter 3.
Mini hydropower	The definition of a mini hydro project varies but a generating capacity of up to 10 megawatts (MW) is generally accepted as the upper limit. This makes the technology suitable for low-head applications.
Nadir pressure	The lowest point of pressure measured.
Overshot weir	Weir where water flows over the top of a gate. The height of the gate can be fixed or adjustable.
Ratio of pressure change	The change in pressure that a fish experiences between the pressure it is acclimated at (neutrally buoyant) prior to passage and the lowest pressure (nadir) experienced during hydropower turbine passage. This ratio governs the degree of change in volume of the fish swim bladder during decompression and is a primary determinant in barotrauma related injury.
River infrastructure	Refers to any man-made structure placed within a natural or man-made waterbody for the purposes of intercepting, regulating or diverting river flow (e.g. Dams, weirs, regulators or hydropower facilities).
Shear (Fluid)	Fluid shear occurs when two water masses of different velocities intersect or are adjacent to each other.
Sensor Fish	An autonomous device containing gyrometers, accelerometers and pressure and temperature sensors that is released through river infrastructure to better understand the hydraulic conditions experienced by fish during passage (Figure 5).
Undershot weir	An adjustable weir where water flows beneath the gate.

Boys et al. *Development of fish screen criteria*

1. GENERAL INTRODUCTION

1.1 Background

Society has invested in dams and weirs to regulate river flows, divert water for agricultural, domestic and industrial needs and to generate hydropower. Hydropower is currently the largest source of renewable energy globally, contributing nearly 16 % of the world's total energy production in more than 160 countries. Further development is likely through the implementation of global climate change policies (Geoscience Australia and ABARE 2010). Whilst regions like China, North America, OECD Europe, South America and Africa are expected to continue to utilise large-scale hydroelectricity generation (Geoscience Australia and ABARE 2010), much of the growth in hydropower is expected to be in small-scale or mini hydropower (typically less than 10 MW) especially in regional and developing countries (Paish 2002).

Although hydropower contributed 63% of the renewable energy mix for NSW in 2011 (NSW Government 2012), low topography and variable rainfall in south-eastern Australia will limit further development of large-scale hydropower (Geoscience Australia and ABARE 2010). There is, however, potential to utilise existing weirs, flow control structures and irrigation supply networks for low-head (< 6m) hydropower installations, and the feasibility of mini hydropower technologies is being explored in the Murray-Darling Basin and in coastal catchments. Currently, mini hydro is the most frequent type of hydropower plant within Australia, accounting for 54% of all projects in 2009 (Geoscience Australia and ABARE 2010). It has been estimated that there may be more than 1,000 MW in potential further generation on several dozen sites throughout NSW (NSW Government 2012). As an example a new 3.7 MW hydropower plant was completed at Prospect Reservoir in Western Sydney in late 2012.

Some of the reasons put forward by groups investigating the feasibility of mini hydro projects within south-eastern Australia relates to the potential use of existing infrastructure to generate new economies beyond water delivery for agricultural purposes, encouraged by governments wishing to explore all possible alternatives to carbon-intensive power generation (NSW Government 2012). It is inevitable that a lower reliance on fossil fuels will require a mix of renewable technologies. What that mix may look like (and what proportion will be contributed by mini hydropower) is uncertain, however, it will come down to informed trade-offs being made between the social, economic and environmental costs and benefits. Hydropower development needs to balance the social and economic benefits from renewable power generation with safe fish passage to guarantee the protection of migratory fish populations.

Freshwater fish comprise 41% of the world's fish fauna (Leidy and Moyle 1998), but are the second most endangered vertebrate group after amphibians (Saunders *et al.* 2002). The proliferation of river infrastructure and flow regulation has been implicated as a major cause of global declines in freshwater ecosystems (Dudgeon *et al.* 2006, Venter *et al.* 2006). Man-made structures fragment habitats and alter hydrology which can disrupt flow-dependent life history strategies such as spawning and recruitment (Walker 1985, Humphries and Lake 2000, Humphries *et al.* 2002). River infrastructure can prevent or delay upstream and downstream migrations (Caudill *et al.* 2007), or physically remove individuals from river populations (Moyle and Williams 1990, Musick *et al.* 2000). Dams, weirs and hydropower facilities can also create adverse hydraulic conditions such as rapid pressure changes and turbulence which can injure or kill fish during downstream passage (Neitzel *et al.* 2004, Baumgartner *et al.* 2006, Deng *et al.* 2010, Brown *et al.* 2012a). The implication of reduced survival can be huge for populations of anadromous species, where safe downstream migration of juveniles is a critical life history requirement (Ebel 1981), but it is no less significant for freshwater species that undertake downstream movements entirely within freshwater environments to recolonise habitats, feed and breed (Coutant and Whitney 2000, Lintermans and Phillips 2004).

Given the recognised risks on river ecosystems of river infrastructure, it is prudent that any further development of hydropower projects, regardless of the social or economic benefits, be done in a way which does not further threaten the sustainability of fish or other aquatic fauna. A number of native fish species are listed as threatened under State and Federal legislation. Works associated with implementation or maintenance of river infrastructure can also trigger approval requirements under State and Federal environmental planning and biodiversity conservation legislation. If a development is likely to have a significant impact on listed threatened species, such as native fish, it triggers a higher level of environmental assessment and the likely imposition of costly mitigation and management measures to address these impacts, which can affect project viability. Therefore, the ramifications for new infrastructure which may adversely impact on fish may be both environmental and economic.

There remains some uncertainty regarding the risk faced by threatened fish populations from new hydropower developments. A risk assessment of any new development should consider both the consequence and likelihood of adverse environmental impacts (Turnpenny *et al.* 2000). In the instance of fish passage at hydropower plants, the consequence (injury or mortality) and the likelihood that fish will be exposed to adverse hydraulic conditions remains unclear in Australia. Uncertainty arises because most published research from which to make judgement concerns non-Australian species, primarily juvenile salmonid species passing through high-head Kaplan turbine systems (Coutant and Whitney 2000, Brown *et al.* 2012a, Brown *et al.* 2012b). No data is available on the lethal and sub-lethal effects of hydropower turbine passage for Australian species and for the various life history stages that are known to undertake downstream migrations (Lintermans and Phillips 2004). There is also uncertainty about the degree of injury sustained by fish passing downstream through existing weirs and regulators, although preliminary studies suggest that this may be significant for certain species and life history stages at some structures (Baumgartner *et al.* 2006). Hydropower technology is also evolving rapidly and, in the mini hydro sector in particular, non-turbine systems are becoming available which purport to generate hydraulic conditions which make them a safer option for fish passage (Odeh and Sommers 2000), although many of these claims remain untested on fish.

Uncertainty surrounding the risk faced by migrating fish in mini hydropower projects in Australia is hampering informed decisions being made about the environmental sustainability and potential expansion of this industry. It was the objective of this twelve month project to develop the research capacity required to address this uncertainty. Ultimately a research program will be developed which specifically quantifies the likely risk of injury and mortality faced by fish at future proposed developments. Such research would provide fisheries management authorities and project developers with the information required to develop suitable mitigation strategies, whether through improved design or operational modifications.

The current project sought to determine what questions need to be addressed through targeted research in order to provide developers and fisheries authorities with the confidence to make informed design and policy decisions regarding future mini hydropower developments. The ultimate objective being to establish the research and development capacity within NSW to facilitate improvements in passage conditions for fish species (including threatened species) at river infrastructure, as well as enhance the State's capacity to implement new, sustainable energy technologies in regional areas.

As part of this project, the NSW Department of Primary Industries (Fisheries NSW) and the Water Research Laboratory (University of NSW) were commissioned to undertake the following activities, the outputs from which are outlined in this report:

1. Preparation of workshop proceedings to identify key research questions and identify the resources and facilities required to develop bio-design criteria for mini hydropower in NSW, and to seek guidance on the consent or approval process (Chapter 2 and Appendix 1).
2. Disseminate results obtained from Computational Fluid Dynamics (CFD) modelling and direct measurements of hydraulic conditions experienced by fish during 'undershot' gate passage at Hay

Weir on the Murrumbidgee River (Chapter 3). These data will provide some indication of the ‘baseline’ hydraulic conditions faced by fish at weir structures, thus informing hydraulic ranges to be tested in future laboratory experiments and allowing direct comparison to future mini hydropower projects.

3. Design and construct research facilities to determine critical tolerances of fish to rapid pressure changes and turbulent shear (Chapter 4).
4. Identify research procedures and suitable experimental designs for laboratory studies aimed at determining critical hydraulic thresholds for the injury and mortality of native fish species during different life history stages (Chapter 5).

2. RESEARCH DEVELOPMENT WORKSHOP

With contribution by Roy Barton.

2.1 Introduction

2.1.1. Purpose of the workshop

The purpose of the workshop was to seek agreement amongst the fisheries management authorities, researchers and development companies, as to *the requirements that must be met to enable the development and initiation of a research program* to inform the application of fish-friendly, mini hydropower facilities in NSW.

2.1.2. Context of the workshop

It is recognised that fish passage through large turbines at high-head hydropower installations can result in injury as a result of sudden pressure changes, physical strike with turbine blades and damage from fluid shear (Neitzel *et al.* 2004, Deng *et al.* 2005, Brown *et al.* 2012a). United States researchers have made significant progress in determining the critical thresholds of these hydraulic parameters which minimise impacts on fish and from these, engineers are redesigning turbines to improve fish passage survival. As understanding of the mechanisms responsible for fish injury improves, so too does the capacity to deliver more environmentally friendly hydropower installations, through better turbine design and operation (Deng and Carlson 2012).

Throughout Australia and internationally, action on climate change and the desire to generate renewable energy has created increased interest in new mini hydropower projects using existing river infrastructure networks (Paish 2002, Geoscience Australia and ABARE 2010). The lower operating head of mini hydropower systems has the potential to reduce the impacts on fish when compared to high-head Kaplan turbines, but this remains untested and there is concern over the suitability of mini hydropower in natural river systems, where threatened populations of migratory fish are found (Larinier 2008). Further research into the ‘fish-friendly’ technologies is needed (Larinier 2008) and new designs need to be evaluated to inform the environmental assessment process. Within NSW, this will involve expanding on research carried out in other parts of the world with the direct investigation of native Australian fish species.

A workshop was convened to bring together representatives of fisheries management authorities, researchers and development companies to seek agreement as to the requirements that must be met for the development and initiation of a research program aimed at addressing knowledge gaps. Twenty four participants from a range of agencies from Australia, Lao PDR and the United States participated in the workshop held in Sydney in November 2011. The workshop was facilitated by the Australian Centre for Value Management Pty Ltd (ACVM). Full proceedings of the workshop were prepared by Roy Barton of ACVM and are presented in Appendix 1 of this report.

2.2 Canvassing different points of view and reaching a consensus

Various workshop presentations were given outlining the motivation driving an emerging mini hydropower industry in south eastern Australia and identifying the primary concerns that fisheries scientists and management authorities have over this expansion. Mini hydropower was identified as a technology that could promote social and economic growth in regional communities of NSW and contribute to renewable energy targets at the State and Federal Government level. Australian and international fisheries scientists raised concerns over international examples demonstrating some of the impacts of hydropower on fish, although it was noted that this may not necessarily apply to all low-head and mini hydropower technologies and that some progress has been made recently by engineers and biologists in developing more ‘fish-friendly’ design options. Much of the uncertainty within NSW exists due to a lack of rigorous evaluation of hydropower within an Australian context and results from other research which shows that fish injury and mortality has the potential to be significant via existing routes of downstream passage at some weirs (Baumgartner 2005). Based on these uncertainties, fisheries management authorities want to know how potential technology works in practice and how it will be deployed and operated in the field. Managers also need to know the likelihood and significance of impacts in general on native fish and threatened species and whether this will prompt further environmental assessment and mitigation/management requirements for the proponent. Developers made the point that other countries have well-developed construction guideline documents to help mitigate potential impacts and raised concerns that no such guidelines exist in Australia and are urgently needed.

There was general agreement among participants on several requirements needed to inform the process of mini hydropower development including:

1. Enhanced knowledge on the ability for native fish to safely pass through mini hydropower systems;
2. Production of a clearly-defined set of acceptable biological criteria for mini hydropower operation and construction;
3. Experimental field validation that newly-developed designs are ‘fish-friendly’, preferably in low-risk habitat (such as an irrigation offtake regulator); and
4. Improved understanding of how research outputs would be integrated into the development assessment process.

2.3 Research Program Development

Participants collectively agreed that a structured research and development program, using a combination of laboratory and field-based trials (Table 1), could address many of the uncertainties regarding fish passage at mini hydropower plants and facilitate recommendations being made as to how to mitigate any risks. The key objective of a research program should be to provide a scientific platform on which to base informed decisions regarding the expansion of mini hydropower developments in environmentally sensitive areas. Laboratory trials would seek to identify the critical tolerances of Australian fish to pressure change, shear stress and blade strike. These experiments would be best applied within an adaptive management framework, where information of the critical tolerances of fish can be used to develop pragmatic ways of mitigating risks, through improvements in design or operation. Given the potential for emerging mini hydropower markets throughout Australia and south-east Asia, and given the extensive body of work already underway in the U.S., it was felt that there would be significant value in continuing to foster a collaborative research effort throughout the Asia-Pacific region.

Figure 1. Workshop delegates inspecting Hay Weir (Murrumbidgee River). From left: Andrew Jones (Waratah Power), Soulivanthong Kingkeo (National Agriculture and Forestry Research Institute), Daniel Deng (Pacific Northwest National Laboratory), Craig Boys NSW DPI , Richard Brown (PNNL), Lee Baumgartner NSW DPI , Oudom Phonekhampeng and Garry Thorncraft (National University of Lao).

Table 1. Research needs proposed as being important either pre- or post-construction.

PRE-CONSTRUCTION

Field-based investigations

- Sensor Fish trials – quantify baseline pressure / shear / velocity etc.
- Compare: undershot weir / overshot weir / proposed hydro / natural river channel.
- Investigate 'real world' actual mortality at undershot gates.
- Perform combined Sensor Fish / live-fish studies with different release depths to determine potential factors influencing welfare.
- Determine which fish species are located at the proposed site, and which of these may be impacted.
- Design a before/after study to look into potential benefits/impacts after construction.
- Consider both lethal and sub lethal effects.

Lab-based investigations

- Barotrauma work: determine what the critical tolerances for fish are and at what life history stage they are most vulnerable.
- Shear flume: determine what the critical values of shear are and whether these differ among species and life stages.
- Collate fish-movement information to categorise/prioritise the risk to migrating species in the region (desktop study).
- Additional knowledge needs:
  What level of mortality is acceptable?
  What percentage of the population must be passed to sustain existing populations?

POST-CONSTRUCTION

Field-based investigations

- Determine if the hydropower plant meeting biological performance standards.
- Determine if the hydropower plant improves on current routes of downstream passage (e.g. undershot weir). Determine if the fish community recovering as expected.
- Sensor Fish: determine if actual hydraulic conditions meet expected conditions (first site only).
- Blade strike: Determine the expected losses of fish through blade strike and which species are susceptible.

Continue before / after work.

3. CHARACTERISING BASELINE PRESSURE AND SHEAR CONDITIONS DURING DOWNSTREAM PASSAGE THROUGH AN UNDERSHOT WEIR

3.1 Introduction

Undershot weirs (that discharge water underneath a sluice gate) can cause significantly higher levels of injury and mortality to fish species in Australia's Murray-Darling Basin than overshot (spilling) weirs (Baumgartner *et al.* 2006, Baumgartner *et al.* in press). The exact mechanism by which this occurs remains unclear, although it is thought that a downstream moving fish may be exposed to areas of rapid decompression, elevated turbulence and fluid shear forces and collision with hard structures (e.g. the gate or crest) whilst passing beneath an undershot gate (Baumgartner *et al.* in press).

Decompression and turbulent shear have been linked with fish injury and mortality under both simulated laboratory conditions and during live fish trials at hydropower and bypass facilities (Neitzel *et al.* 2000, Neitzel *et al.* 2004, Deng *et al.* 2006, Deng *et al.* 2010, Brown *et al.* 2012a, Brown *et al.* 2012b). Fish injuries resulting from rapid decompression are referred to as barotraumas and include swim bladder rupture which may in turn result in embolism or haemorrhaging in the fins, musculature and organs (Brown *et al.* 2012b). Fluid shear occurs when two water masses of different velocities and direction interact (Cada *et al.* 1999). A fish caught between two interacting water masses experiences fluid shear; the size of which is determined by velocity and weight of water. If the combined force exceeds the critical threshold that the fish can withstand, then it is likely to be injured (Guensch, *et al.*, 2002). Fluid shear events can result in loss of scales, haemorrhaging, and eye, skin and skeletal damage (Neitzel *et al.* 2004).

By understanding the mechanisms and potential for fish injury and mortality at existing structures and current routes of downstream passage, it will be possible to make more informed decisions regarding the relative change that might be expected from new hydropower installations. Knowing 'baseline' hydraulic conditions at structures is also fundamental to ensure that any laboratory testing on fish is done over ranges of pressure and shear that are likely to be experienced in the field.

The objective of this study was to determine the hydraulic conditions (relating to pressure, turbulent shear and collision) that fish may experience when migrating downstream through undershot weirs under a variety of head scenarios. Field measurements taken at the weir with an autonomous sensor were analysed alongside data generated by computational fluid dynamics (CFD) modelling under a range of flow scenarios. The information gathered on the estimated ranges of decompression, shear and collision expected at both an undershot weir and a mini hydro facility will be used by researchers to inform the design of subsequent laboratory mortality trials.

3.2 Methods

3.2.1. Site details

The Murrumbidgee River is the third largest river in the Murray-Darling Basin, being 1690 km long and draining a catchment of 84,000 km^2. The river is heavily regulated, in order to supply irrigated agriculture, by two large dams in the upper catchment and several smaller weirs in the lower reaches. The structure under investigation in this study is Hay Weir (Figure 2). Hay Weir is a re-regulating structure 47 m wide and consisting of three 13 m wide undershot gates that can be hoisted vertically to generate varying slot widths to vary discharge (Figure 3). Water discharged over the crest of the weir (under the gate) falls 6.7 m over a horizontal distance of 6 m where it then flows over a single row (7.5 m wide) of concrete blocks to dissipate energy (Figure 4).

Figure 2. Location of the Hay Weir study site on the Murrumbidgee River.

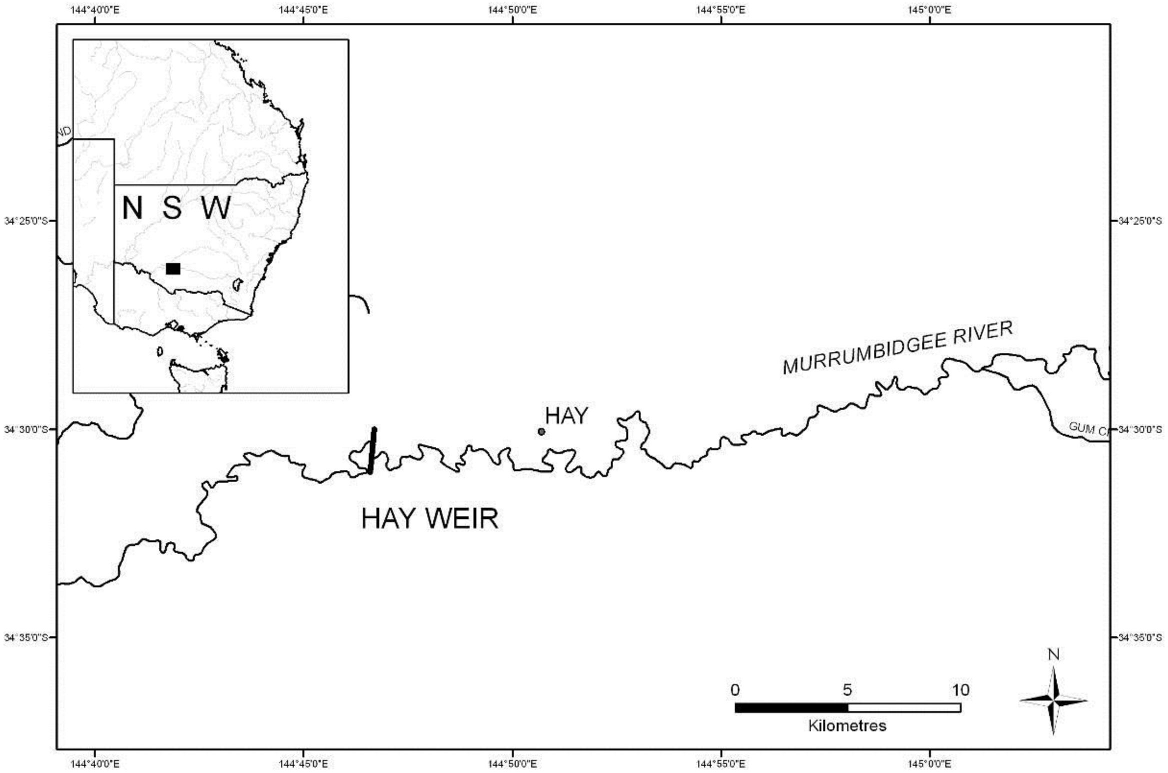
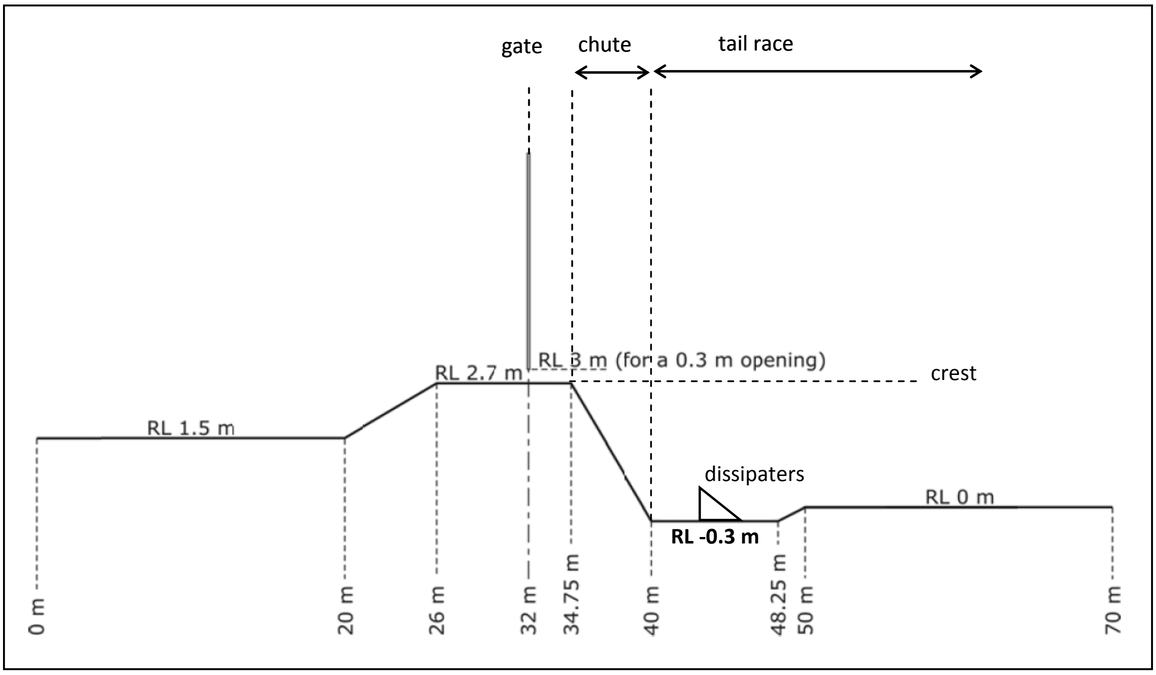


Figure 3. Hay Weir

Figure 4. Idealised cross-section of Hay Weir (not to scale).



3.2.2. *Sensor Fish releases*

The Sensor Fish (Figure 5) is an autonomous device developed by the Pacific Northwest National Laboratory to better understand the physical conditions experienced by fish during passage through hydroturbines and other dam bypass alternatives (Carlson and Duncan 2003). It is 24.5 mm in diameter and 90 mm in length, weighs 42 g, and is almost neutrally buoyant in fresh water. Inbuilt sensors measure linear acceleration in three directions (up-down, forward-back, and side-to-side), angular velocity in three angles (pitch, roll and yaw), and absolute pressure and temperature (Deng *et al.* 2007a). Analysis of these data permits detailed assessment of the fish passage route and identification of potential significant exposure events such as decompression, collisions, strike, shear and severe turbulence. The data generated by Sensor Fish have proven useful in interpreting biological test results by linking potential injurious exposures with live test fish injury and mortality observations (Deng *et al.* 2006).

Sensor Fish were deployed at Hay Weir to benchmark hydraulic conditions. Hay Weir is a three gated structure but at the time of Sensor Fish release (17/1/2012), only the middle gate was opened to 3.3 m above crest level. The upstream pool level was 8.2 m and the overall head differential was 5.8 m. River discharge at the time of release was 1,880 ML/day (measured at gauge 410136 downstream of Hay Weir). Sensor Fish were deployed upstream of the open gate, down a 50 mm diameter PVC tube that was secured to an upstream buoy to ensure mid–bay deployment at 3 m depth and 5 m upstream of the gate. Sensor Fish deployment was facilitated by plunging a rod down the length of the delivery tube. The Sensor Fish then passed under the gate and was recovered downstream of the weir by boat. Balloon tags attached to the Sensor Fish inflated between two and three minutes after deployment, and a directional radio receiver antenna was used to locate the device which was also fitted with a small radio transmitter (Figure 6). The balloon tags contained two gelatine capsules containing equal parts bicarbonate soda and acetic acid powder. Immediately prior to release, 7 mm of water was injected into the neck of each balloon which were subsequently sealed using cable ties. The gelatine capsules delayed the mixing of water and the dry powders, which eventually resulted in the release of carbon dioxide and inflation of the balloons. Once recovered, data were uploaded from each Sensor Fish onto a computer for analysis.

Figure 5. The Sensor Fish device showing the location of the measurement axes for the three rate gyros (that measure angular velocity, ω, three linear accelerometers (that measure the acceleration, a), and pressure transducers (source Deng *et al*. 2007a).

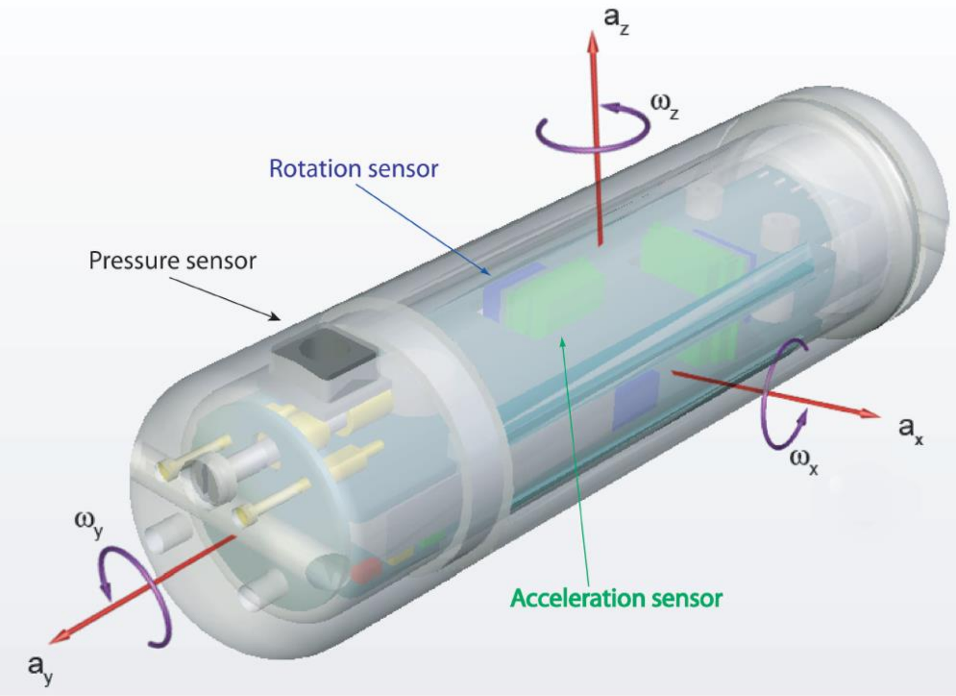
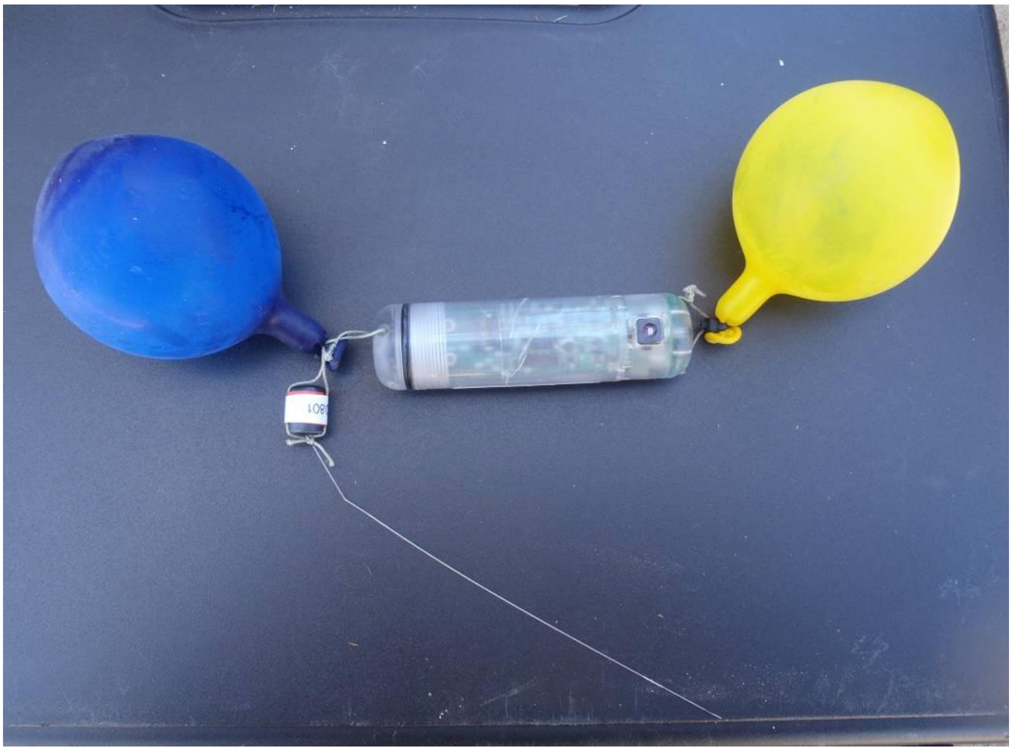


Figure 6. Sensor Fish showing balloon tags (inflated/recovered state) and radio tag attached to assist in recovery downstream of weir.



3.2.3. Sensor Fish data analysis

Sensor Fish data consist of time histories of pressure, acceleration (*x*, *y*, and *z* axes), angular motion (pitch, roll, and yaw), temperature and time extending from the time of sensor triggering for a pre-programmed number of seconds. The sampling frequency is 2,000 Hz or one reading every 0.005 seconds (Deng *et al.* 2007a). All devices were calibrated at time of manufacture to ensure relative errors of both the linear acceleration and angular velocity measurements were less than 5%. Pressure sensors were calibrated at time of manufacture and subsequently tested in a barometric chamber of known pressure to ensure readings were within the acceptable error range of +/- 0.2 psi.

Pressure data were used to estimate Sensor Fish depth and to divide passage time into segments corresponding to specific locations (zones) from deployment to tailwater entry (Deng *et al.* 2007b). For a typical Sensor Fish released in the middle of a the bay at Hay Weir, these zones were passage down the deployment tube (T0-T1), the approach to the gate (T1-T2), transition under the gate (T2-T3), down the spillway chute (T3-T4) and into the tailwater (Figure 7). These zones were identified from distinctive signature events (Figure 9), which also allowed the probable location and time of collision or shear exposure events to be estimated and to enable Sensor Fish data to be interpreted alongside CFD results.

The approach of Deng *et al.* (2007a) was used in this study to characterise shear and collision events from acceleration and rotational data. When Sensor Fish contact solid structures (such as crests or gates) or are impacted by turbulent shear, high-amplitude impulses occur in the acceleration and rotational velocity time history. Observations of Sensor Fish and salmon smolt in a laboratory flume show that changes in magnitude in excess of 25 *g* can lead to fish injury (Deng *et al.* 2005, Deng *et al.* 2010) and in the absence of similar information for Australian species, this criterion was used as a threshold value to identify exposure events. Collision and shear events can then be differentiated on the basis that a collision event creates a much narrower peak in acceleration and rotational velocity than does a shear event (Figure 8). Peak duration was defined as the duration of acceleration within 70% of the peak value, and collision and shear events were distinguished by the following criteria: 1) the event was a collision if peak duration was less than 0.0075 second (Figure 8a); 2) the event was a shear event if peak duration was longer than 0.0075 second (Figure 8b). Pressure and rotational measurements were then used for validation of the classification (Figure 8c & d).

Figure 7. The key zones of Sensor Fish passage through an undershot gate at Hay weir. T1-T4 correspond to points in space shown in Figure 9. Not to scale

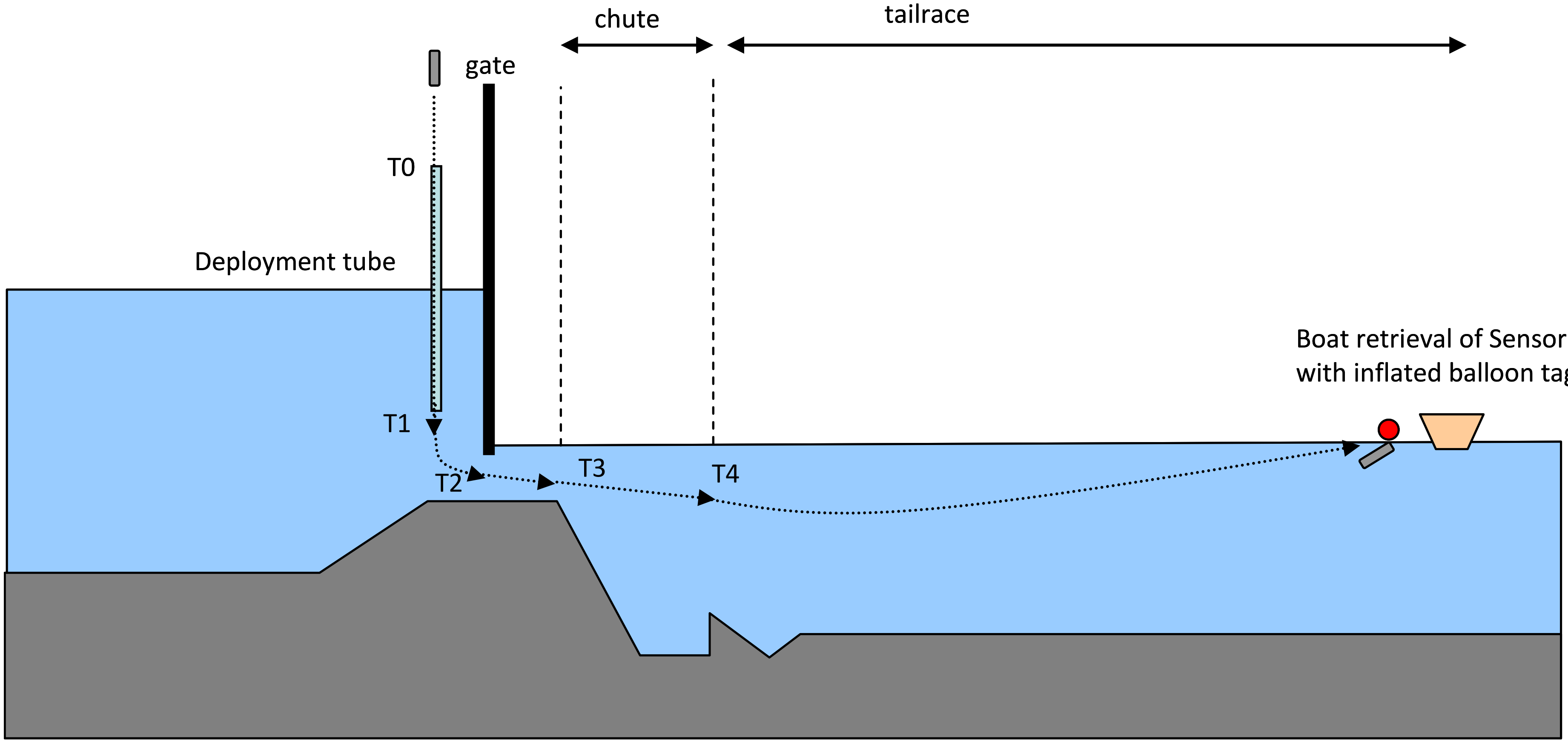
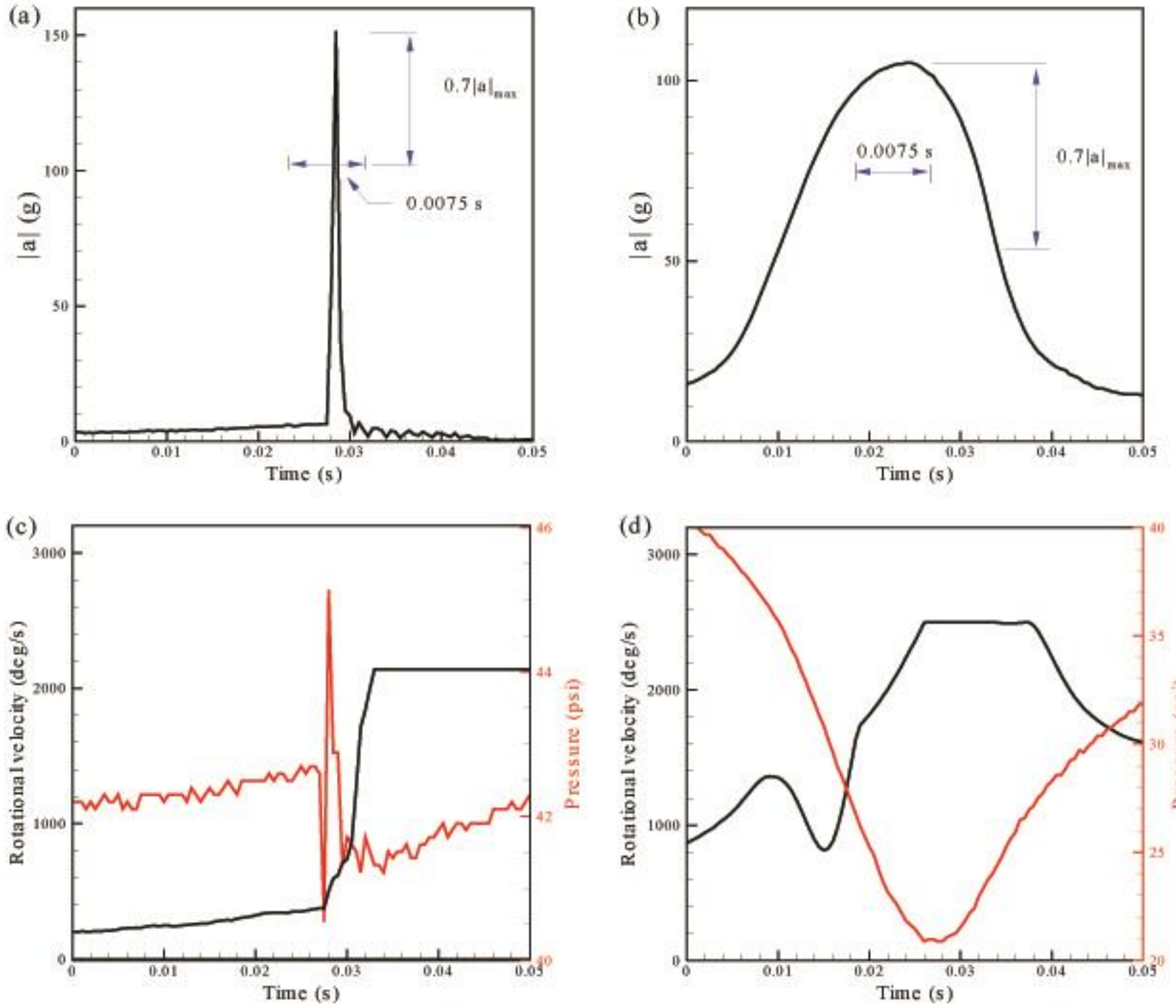


Figure 8. Criteria used to distinguish between a collision and shear event using velocity data measured with the Sensor Fish. Duration of acceleration with 70 % of the peak value is a) < 0.0075 seconds for a collision event, and b) > 0.0075 seconds for a shear event. Pressure and rotation also increase more markedly during a c) collision event than during a d) shear event (source Deng *et al.* 2007a).



3.2.4. *CFD modelling*

Sensor Fish can measure actual hydraulic conditions that are difficult to model using Computational Fluid Dynamics. But Sensor Fish is limited by the fact that the flow and operational scenarios that can be tested are limited to those present at the time of field surveys. Often it is not possible to change the flow in a river or the operation of a weir to generate the range of scenarios of interest. Because of this, CFD modelling can be a useful and cost-effective way to predict hydraulic conditions over a wider range of operational scenarios. The Water Research Laboratory (WRL) was commissioned by NSW DPI to undertake CFD modelling of flow through the Hay Weir on the Murrumbidgee River.

OpenFoam is an open-source CFD model capable of calculating many hydraulic scenarios. An “InterFoam” solution module was used in this instance, as it is suitable for free surface flow modelling especially where air can become entrained in the fluid, such as the region immediately downstream of a weir. A number of solution methods were trialled. Turbulence closure is a very important component of CFD modelling. The adopted method was the Reynolds Average Simulation (RAS) using the default parameters provided within InterFoam. The model was run as a two-dimensional vertical slice. Weir geometry was idealised (Figure 4) from drawings provided to WRL (Water Resources Commission, Works as Executed, Drawing 104/25, 1980). RL 0.0 m was estimated to be the same as the upstream water level measurements (Figure 4). This was based on the bed of the downstream channel being RL 77.5 m AHD, the upstream full storage level being RL 85.5 m AHD and advice from Hay weir operators that 8 m is the maximum upstream depth. The adopted model mesh resolution was approximately 15 mm in the area under the gate expanding up to 200 mm in the slow moving areas upstream.

Upstream water levels were modelled at RL 8 m (full storage) and RL 6.5 m depth (advised as the minimum level observed). These are equivalent to a depth at the gate of 5.3 m and 3.8 m as the gate sits on an elevated crest or sill at RL 2.7 m. The weir was modelled at a range of gate openings: 0.1 m, 0.3 m, 0.5 m, 0.7 m and 0.9 m. The 0.3 m scenario was comparable to the operating conditions experienced during Sensor Fish trials. This resulted in a total of 10 scenarios as summarised in Table 2. Tailwater conditions were kept constant at a low level. Discharge through the weir depends on the upstream water level, the weir opening and the number of gates opened. The width of each gate was taken as 13 m. Table 2 provides an estimate of the total river discharge in each condition using the relationship which assumes that there is no tailwater influence:

$$\textit{Discharge per meter width } (m^3/s/m) = 0.58 * (\textit{opening height}) * \textit{sqrt}(2.g.\textit{Depth at gate})$$

Where: g = gravitational constant

Eight flow paths from random start points were generated per scenario.

Table 2. Equivalent river flows for scenarios considered

Scenario	U/S Level (m)	Depth at Gate (m)	Gate Opening (m)	Discharge ($m^3/s/m$)	Discharge with 1 gate open (ML/day)	Discharge with 2 gates open (ML/day)	Discharge with 3 gates open (ML/day)
S01	8.0	5.3	0.1	0.591	660	1330	1990
S02*	8.0	5.3	0.3	1.774	1990	3990	5980
S03	8.0	5.3	0.5	2.957	3320	6640	9960
S04	8.0	5.3	0.7	4.140	4650	9300	13950
S05	8.0	5.3	0.9	5.323	5980	11960	17940
S06	6.5	3.8	0.1	0.501	560	1130	1690
S07	6.5	3.8	0.3	1.502	1690	3380	5060
S08	6.5	3.8	0.5	2.504	2810	5630	8440
S09	6.5	3.8	0.7	3.506	3940	7880	11810
S10	6.5	3.8	0.9	4.507	5060	10130	15190

* This scenario is comparable to the operating conditions present during Sensor Fish trials.

3.3 Results and discussion

3.3.1. Pressure

Plots of pressure, acceleration and rotation data recorded for the 12 Sensor Fish releases at Hay Weir are shown as full time history plots in Appendix 2 and are summarised in Table 3. The data obtained from all 12 runs were highly repeatable. After release, there was a slight increase in pressure as the fish moved towards the gate and dived to approximately 5 m when entrained (Figure 9). At this point a rapid pressure drop occurred (within 0.25 seconds) as the fish moved from 5 m depth to surface pressure (100kPa) as they passed under the gate (Figure 10). In all cases there was a slight period of 'negative' (or below atmospheric) pressure (94.41-99.79 kPa), when pressure falls below surface pressure prior to reaching the tail race (Table 3 and Figure 11). This was possibly due to the inverse relationship between pressure and velocity (Bernouilli's Principle) and the rapid acceleration which occurs under the gate (Table 3 and Figure 12). Over the complete passage from gate to tailrace a 50 % reduction in pressure was experienced in 0.25 s (Figure 13).

Figure 9. A typical time history trace showing change in pressure, acceleration and rotation during passage under the middle bay gate of Hay weir.

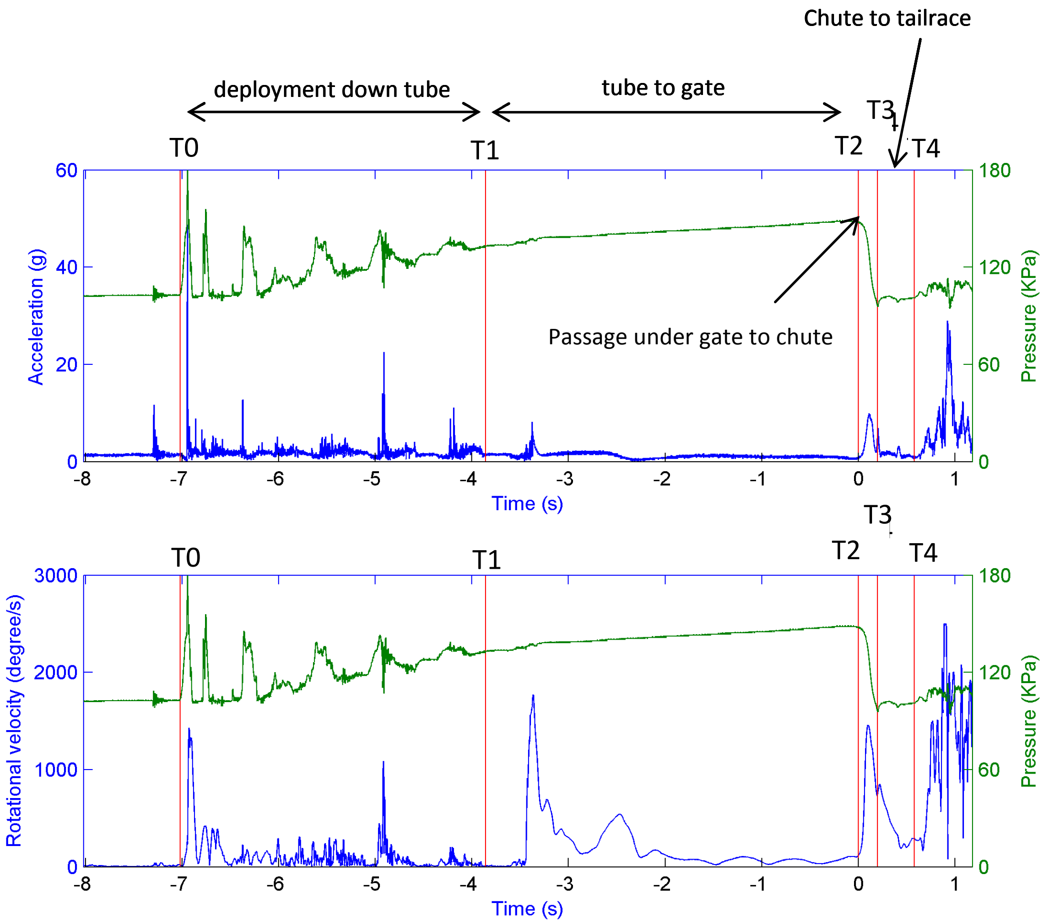


Figure 10. Change in pressure and depth during passage through an undershot gate at Hay weir as measured with a Sensor Fish.

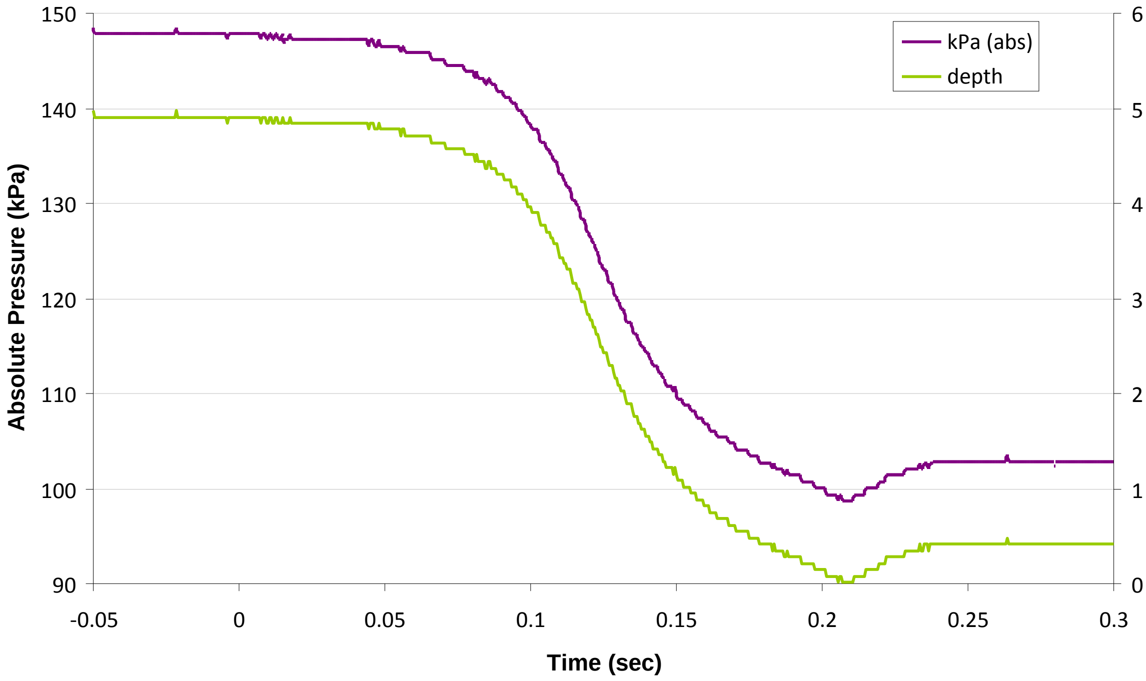


Table 3. Summary measurements for 12 Sensor Fish runs corresponding with different zones of passage.

	Tube to gate							Gate to chute							
	Max Pressure	Min Pressure	Pressure change	% Pressure change	Pressure change speed	Max Accel.	Max Rotation	Depth	Max Pressure	Min Pressure	Pressure change	% Pressure change	Pressure change speed	Max Accel.	Max Rotation
Run	KPa	KPa	KPa		KPa/sec	g	degree/s	metre	KPa	KPa	KPa		KPa/sec	g	degree/s
1	149.64	133.44	16.21	12.14	3.62	5.5	1779.6	4.86	148.95	99.79	-49.17	-33.01	-213.78	13.5	1194
2	148.95	132.82	16.14	12.15	4.18	8.2	1771.4	4.80	148.33	95.72	-52.62	-35.47	-263.08	9.9	1459.1
3	144.95	132.13	12.83	9.71	3.58	6.6	1172	4.45	144.95	95.72	-49.24	-33.97	-205.16	14.3	851.1
4	148.33	132.82	15.52	11.68	4.67	3.6	1615.6	4.80	148.33	95.72	-52.62	-35.47	-202.37	11.2	664.2
5	148.95	134.82	14.14	10.49	3.41	7.7	1567.1	4.86	148.95	99.10	-49.86	-33.47	-262.41	12.4	804.3
6	145.57	126.75	18.83	14.85	7.47	3.4	648.9	4.38	144.26	94.41	-49.86	-34.56	-276.99	12.5	1351.9
7	147.64	130.13	17.52	13.46	4.00	3.5	239.5	4.66	146.95	94.41	-52.55	-35.76	-210.19	11.3	442.7
8	144.95	128.75	16.21	12.59	5.05	3.3	812.8	4.45	144.95	97.72	-47.24	-32.59	-196.82	13	812.2
9	144.95	130.13	14.83	11.39	6.86	2.3	1303.1	4.38	144.26	95.72	-48.55	-33.65	-211.08	16.1	1078.9
10	144.95	130.75	14.21	10.86	6.93	3.4	228.8	4.45	144.95	97.72	-47.24	-32.59	-224.94	18.9	1293.9
11	144.26	129.44	14.83	11.45	8.19	2	302.1	4.38	144.26	97.10	-47.17	-32.70	-214.40	12.3	793.6
12	144.26	128.06	16.21	12.65	8.57	4.3	680.8	4.38	144.26	98.41	-45.86	-31.79	-218.37	15.8	1321.8

	Chute to tailrace					
	Max Pressure	Min Pressure	Max Accel.	Pressure change	% Pressure change	Max Rotation
Run	KPa	KPa	g	KPa		degree/s
1	104.47	99.79	4.2	10.27	10.29	356.3
2	102.47	95.72	6.9	6.98	7.29	850.5
3	98.41	95.72	5.4	8.48	8.86	520.7
4	102.47	95.72	6.5	7.38	7.71	781.2
5	105.16	99.10	4.9	9.47	9.56	510.4
6	99.10	94.41	4.5	9.19	9.73	689
7	101.10	95.03	4.3	9.48	9.98	394.1
8	100.47	97.72	4.2	9.97	10.20	570.2
9	102.47	96.41	2.7	11.28	11.70	894.5
10	100.47	97.72	3.8	10.37	10.61	239.8
11	101.10	96.41	5.8	8.18	8.48	1308.9
12	99.79	97.72	3.5	10.67	10.92	1095.6

Figure 11. Median ± minimum/maximum values of Nadir (lowest) pressures measured over 12 Sensor Fish runs for each zone of passage at Hay Weir.

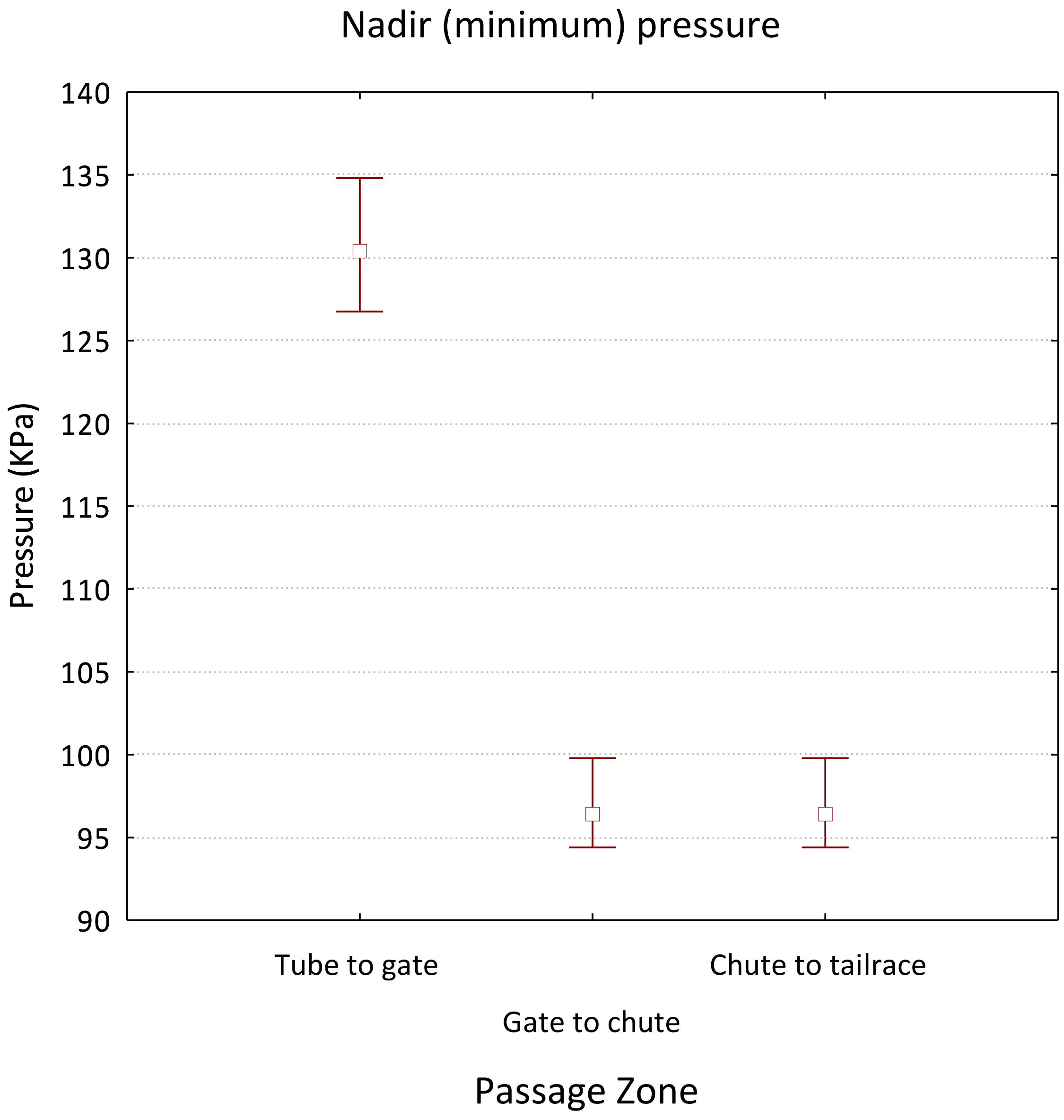


Figure 12. Median ± minimum/maximum values of maximum acceleration measured over 12 Sensor Fish runs for each zone of passage at Hay Weir

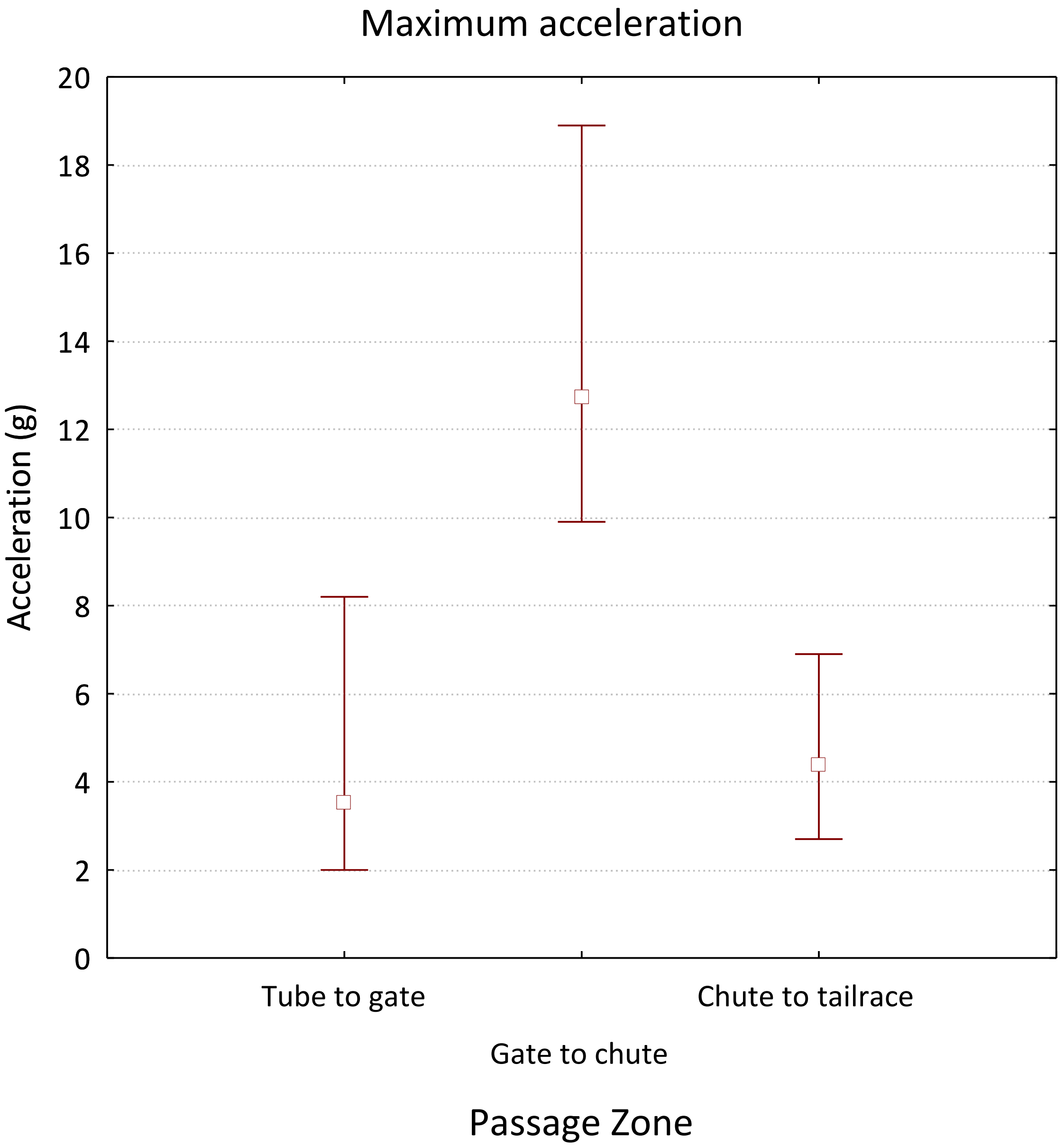


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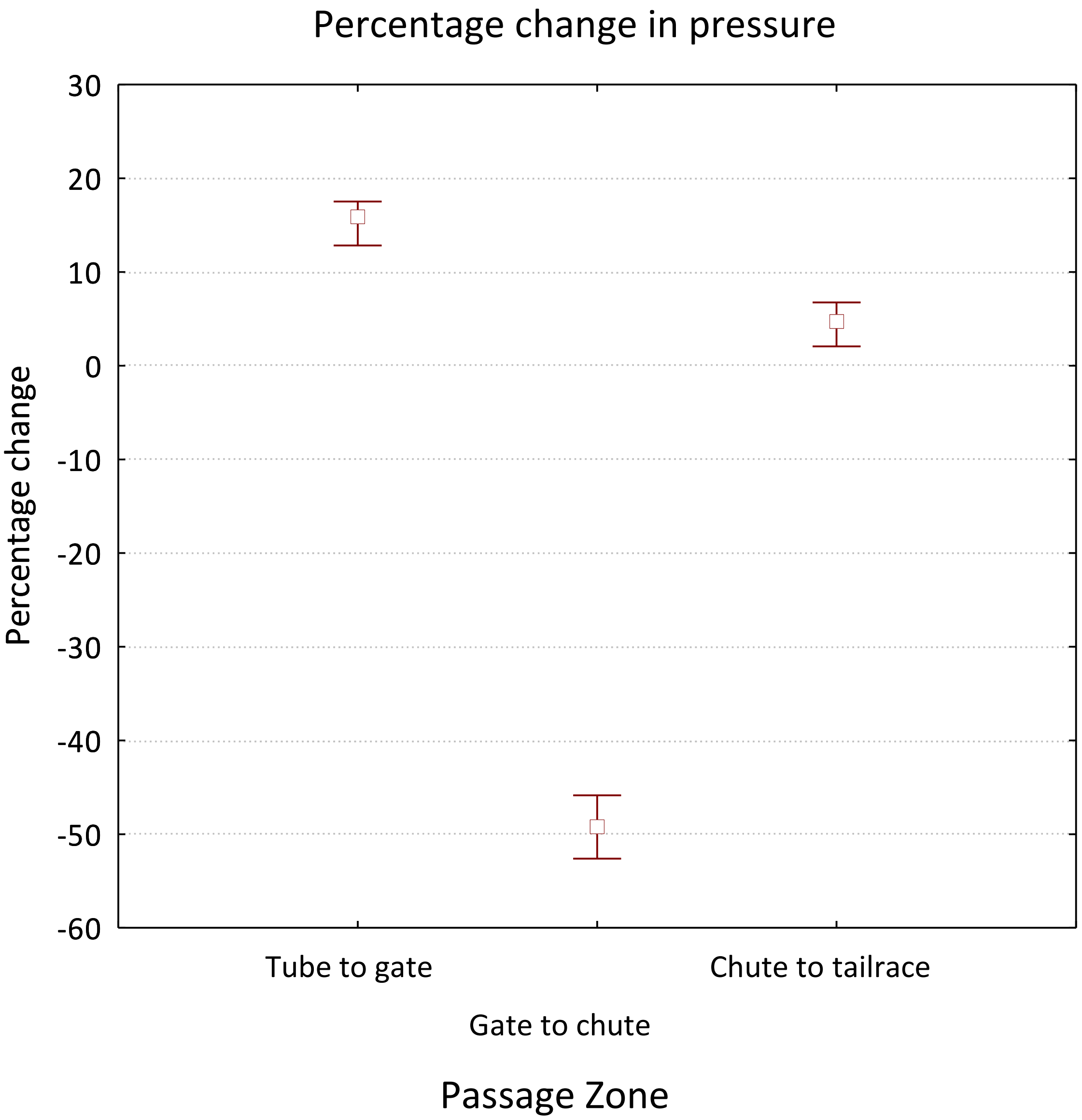
Figure 13. Median ± minimum/maximum values of percentage pressure change measured over 12 Sensor Fish runs for each zone of passage at Hay Weir



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CFD modelling at Hay weir was used to test a larger range of flow and operational scenarios than was possible using Sensor Fish alone. Figure 14 shows a typical flow profile as predicted by the CFD model. Eight flow paths from random start points were run for each of the ten flow scenarios and the summary of pressure changes measured are shown in Appendix 4. A comparison between CFD modelled pressure changes and that measured with Sensor Fish shows that the CFD model was capable of producing the pressure drop and gradient of change with an acceptable level of accuracy (Figure 15). The Sensor Fish all passed the gate at a slightly deeper level than the CFD predicted and all recorded a slight negative (below atmospheric) pressure after the gate which the CFD modelling was unable to reproduce. In comparison only two of the eight CFD runs showed a negative pressure in the chute. It is likely that these inconsistencies resulted from inaccuracies in calculating the correct weir pool height upstream of the weir and some geometry in the actual gate, crest or chute that was not represented in the modelling. By predicting a lower entrainment pressure and in most cases a smaller Nadir (minimum pressure) it is likely that the estimates modelled using CFD were slightly conservative with respect to the ratio of pressure change for various flow scenarios (Figure 16).

Figure 14. Typical flow profile (scenario S10) predicted for an undershot gate at Hay weir. The background red transitioning to blue is the air water content with red being 100% water and dark blue being 100% air. The streamlines predict the path of fish starting at a variety of depths.

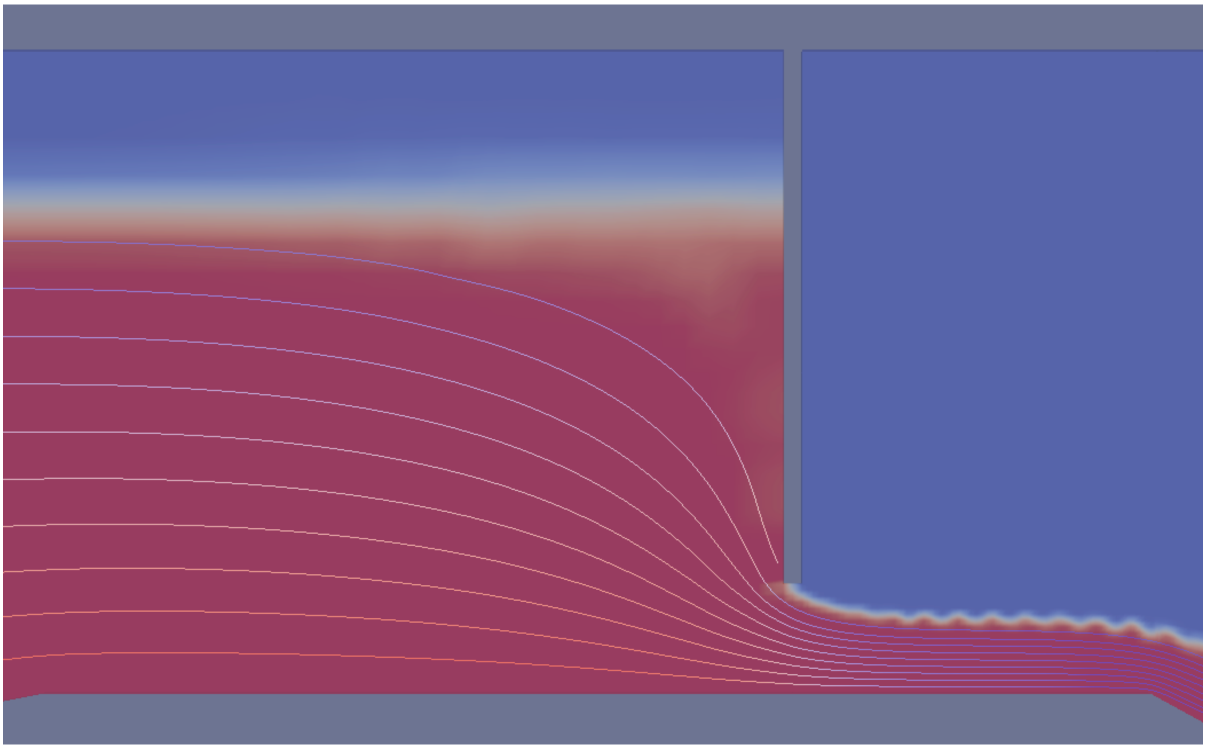
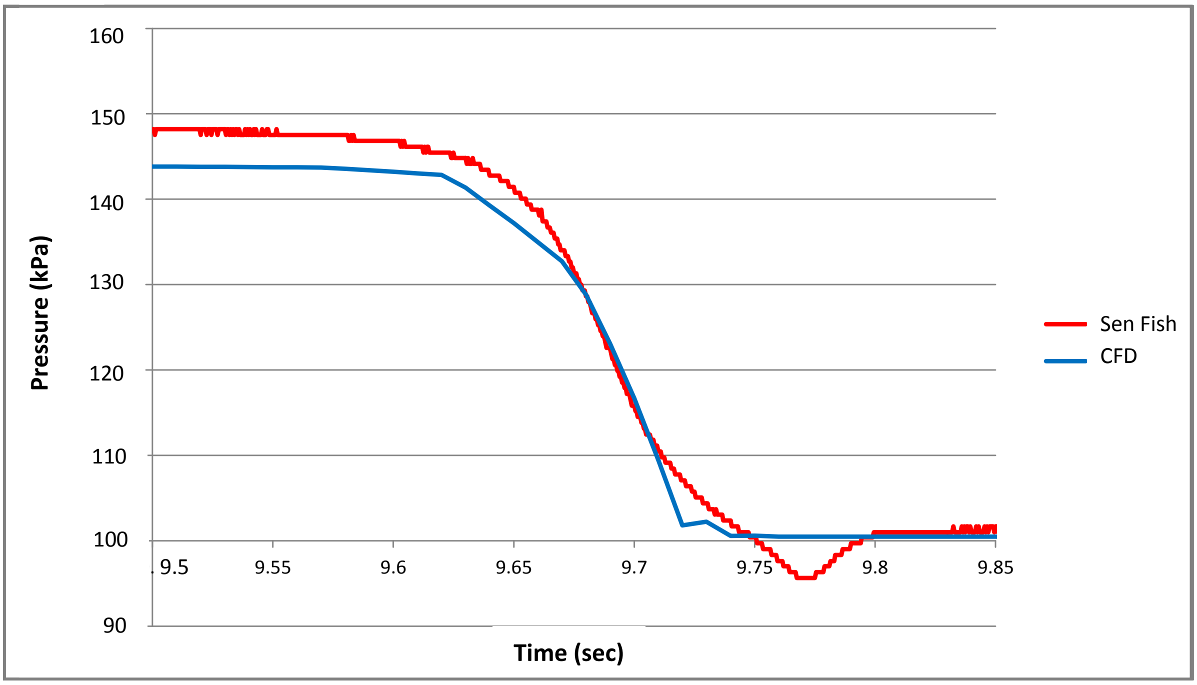


Figure 15. A typical comparison of CFD modelled pressure change and that recorded using Sensor Fish below Hay undershot gate (gate width 0.3 m and upstream weir pool level 8 m; Sensor Fish run 5 comparison to CFD scenario S02).



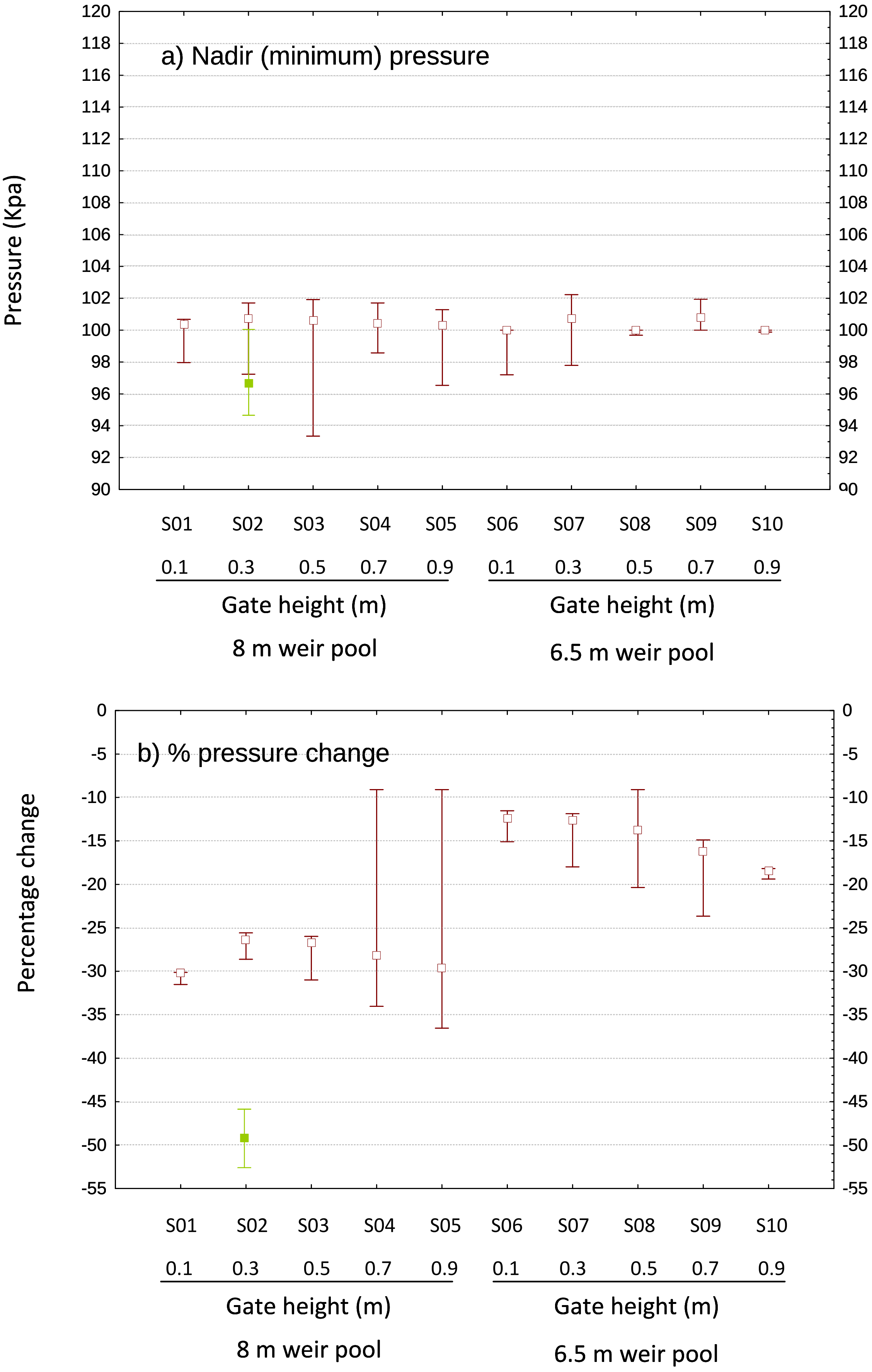
Analysis of the minimum pressures modelled revealed that there was little difference between the nadir experienced during gate passage under the different gate and weir pool height scenarios (Figure 16a). In all scenarios, median nadir pressure was equal to (or slightly higher) than atmospheric or surface pressure (~100 kPa). Minimum modelled nadir values reveal that in some runs, there was the capacity for pressures to fall below atmospheric pressure. In the most extreme case a nadir of 93.35 kPa was observed (S03; Figure 16a and Appendix 3), but the range of nadir was more typically between 96 and 102 kPa). As previously mentioned, slight 'negative' (or below atmospheric) pressure nadirs were also measured with Sensor Fish (median value 96.45 kPa), although these nadirs were slightly lower than predicted by CFD for the same flow scenario (Figure 16a).

Gate height had no significant effect on the percentage pressure change which occurred during passage, but larger pressure falls were modelled when the upstream weir pool level was higher (Figure 16b). This is expected, as nadir pressure did not differ between scenarios, but a greater weir pool height resulted in a greater hydrostatic pressure upstream of the gate. Since the CFD modelling predicted a lower maximum upstream passage pressure than was measured with Sensor Fish, a greater percentage pressure fall was measured by Sensor Fish for the 8 m weir pool / 0.3 m gate height scenario.

3.3.1. Shear and collision

An acceleration value of 25 *g* was selected as the threshold for shear or collision exposure events based on Sensor Fish tests in a laboratory flume (Deng *et al.* 2005). During passage from upstream of the weir gate until transition from the chute to the tailrace, no Sensor Fish experienced any shear or collision exposure events (Table 3 and Figure 12). The CFD modelling supported the Sensor Fish results relating to shear. Peak velocities through the undershot weir of approximately 6 m/sec were predicted. The gradient from the top of the gate to the floor was not significant, but velocity fluctuations of up to double the mean velocity would be considered likely in such fast moving waters. Downstream of the gate, flow paths were not predicted to have significant shear, but shear effects may be caused by local downstream geometry (which was not included in the model). Downstream, the velocities would be lower than through the gate. In summary, the CFD modelling demonstrated gradually accelerating flows being drawn towards the gate opening, with very few areas of sudden change in gradient in velocity (i.e. shear). The modelling indicates that shear flume testing over the range of 2 m/sec to 12 m/sec, would cover all shear conditions expected at such a structure.

Figure 16. Median ± min and max a) Nadir pressure and b) percentage pressure change predicted for various weir pool height and gate opening height scenarios. The green point represents that observed with Sensor Fish.



4. DESIGN AND CONSTRUCTION OF BAROTRAUMA AND SHEAR LABORTORY FACILITIES

The Water Resource Laboratory (University of New South Wales) and NSW DPI were responsible for the design and construction of barotrauma and shear laboratory facilities. Original concept designs were based upon existing facilities at the Pacific Northwest National Laboratory (PNNL) in the USA. PNNL scientists participated in refining concept designs during the November 2011 inception workshop.

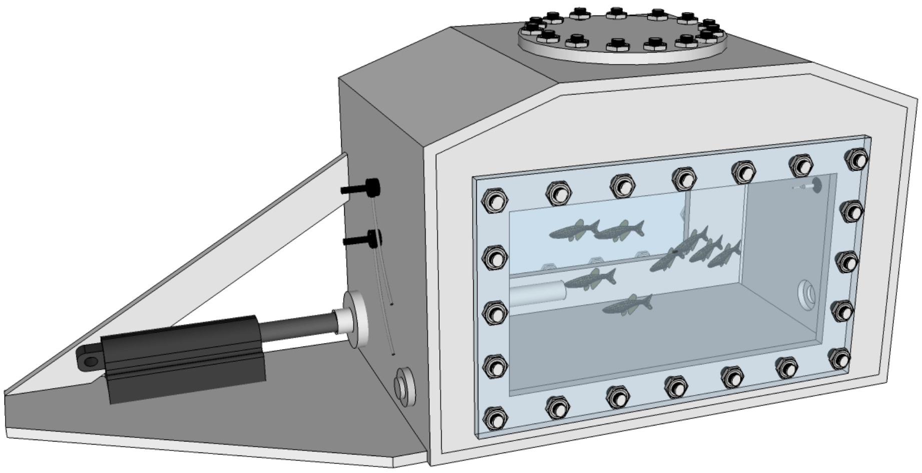
4.1 Barotrauma laboratory

4.1.1. Design specifications

Design specifications for the barotrauma facilities are as follow:

- Two rectangular chambers with a flat glass viewing window at the front (Figure 17).
- The top, bottom and ends are constructed from stainless steel.
- Size of 0.7 m x 0.4 m x 0.4 m with access through a lockable lid on the top.
- The chambers are designed to achieve a maximum decompression from 200 kPa to 10 kPa absolute. This simulates decompression of a fish acclimated at approximately 10 m depth to below surface pressure and is well within the ranges predicted and measured at Hay Weir and will also accommodate the nadir pressures expected at mini hydropower as well as Kaplan turbines at high head hydropower dams.
- Each chamber is fitted with a separate pump and an actuated outlet valve downstream is used to control flow and water pressure in the tank. This allows fish to be acclimated at a desire pressure whilst enabling water to continually flow through the chambers, ensuring dissolved oxygen and water quality is maintained.
- A manually operated ball valve at the inlet and outlet is used to seal the tank during the decompression (trauma) phase. These will eventually be automated and controlled by the software.
- The chambers can maintain an air pocket in the top of the tank during the acclimation phase if physostomous species are being tested. This is essential as these species need to gulp air at the water surface to regulate their swim bladder volume and hence buoyancy. The chambers can be operated without this air pocket for physoclistic species (species that regulate gas exchange physiologically through a vascular rete).
- The rapid decompression (referred to as spiking) which simulates passage is achieved by an electromagnetic actuator with a 25 mm rod moving approximately 100 mm in about 0.25 seconds and equates to the rate of decompression observed at an undershot gate (as determined using Sensor Fish).
- Sensors automatically monitor water pressure, dissolved gas pressure and temperature within the chambers and send these data to the control software.
- The operation of each chamber is automated by its own PC installed with fully integrated control software programmed in Labview (Figure 18). This allows real data obtained by Sensor Fish or data manually determined by the experimenter to be used to generate the desired simulated profiles. The executables can be distributed without the end client needing a Labview licence.
- Four surveillance cameras allow real-time and recorded observations of fish in the chambers (Figure 19).
- The chambers are housed in a 4 m x 2 m x 2 m trailer, creating a self-contained research laboratory capable of being taken to wherever fish can be sourced or research staff are located (Figure 20).

Figure 17. Barotrauma chambers used to generate rapid pressure spikes thereby simulating levels of decompression encountered during fish passage through river infrastructure.



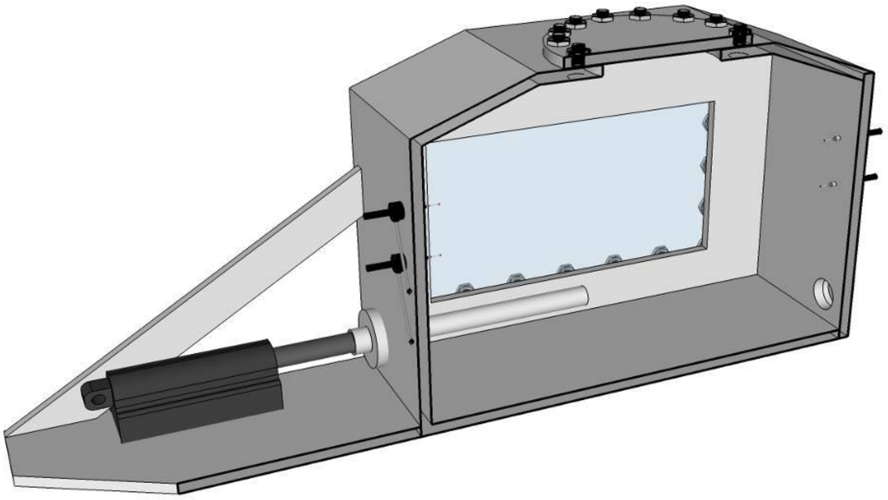
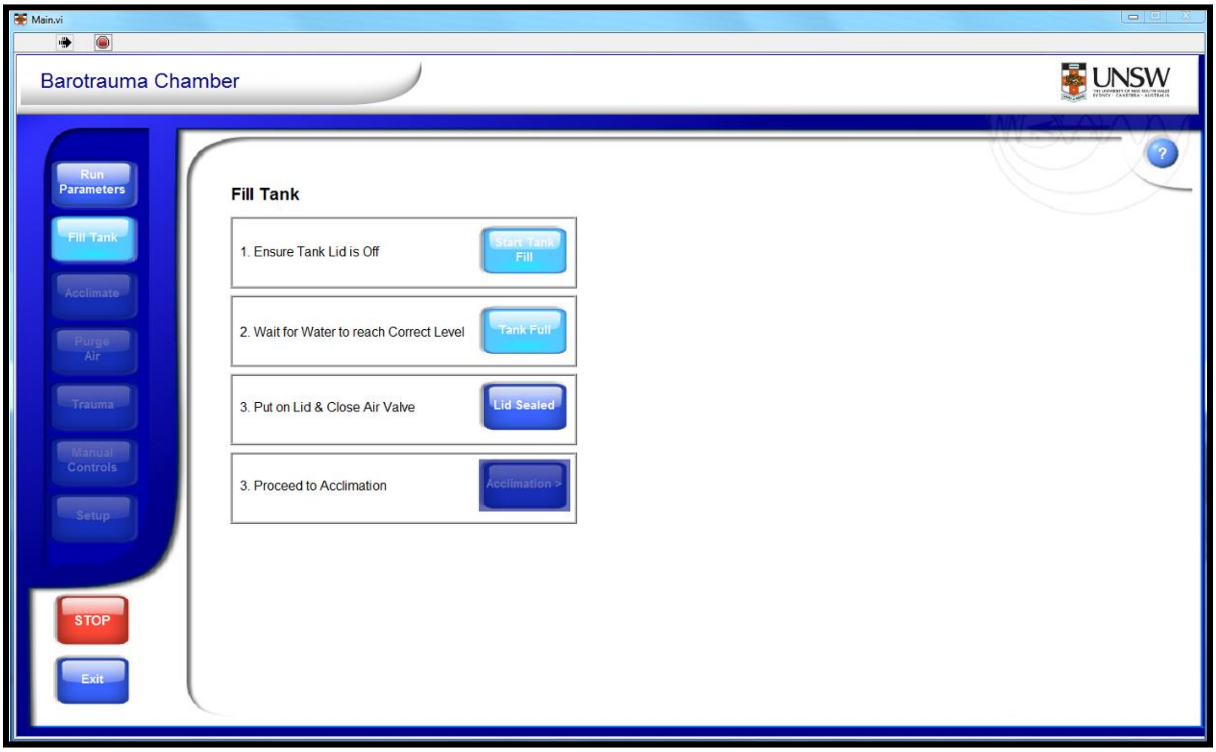


Figure 18. Each chamber is controlled by Labview software where the researcher moves through the procedure in a step-wise fashion guided by the user interface



Fill Tank

1. Ensure Tank Lid is Off

2. Wait for Water to reach Correct Level

3. Put on Lid & Close Air Valve

3. Proceed to Acclimation

.

Figure 19. Surveillance cameras allow unobtrusive observation and recording of fish behaviour (including buoyancy at different pressures).

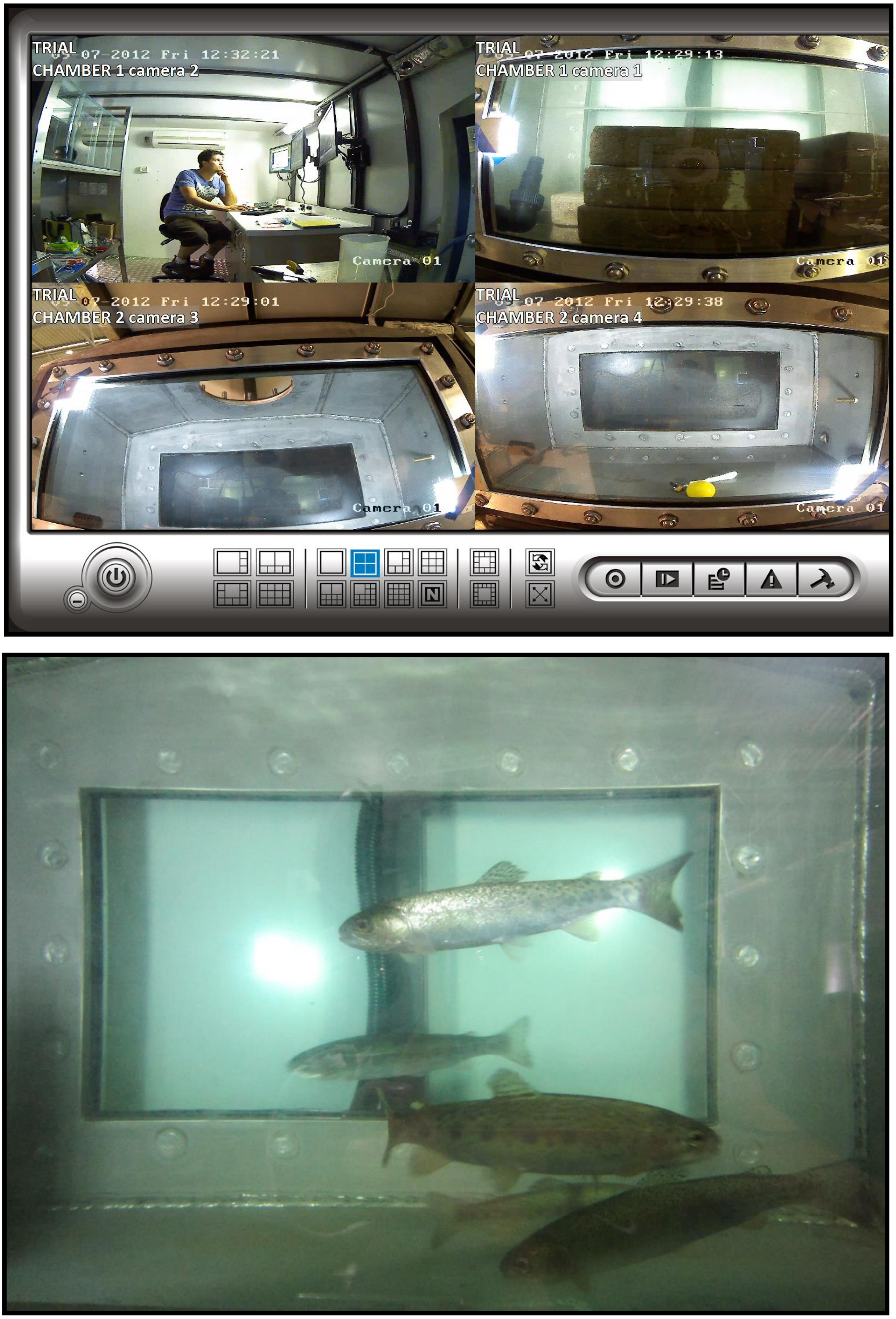
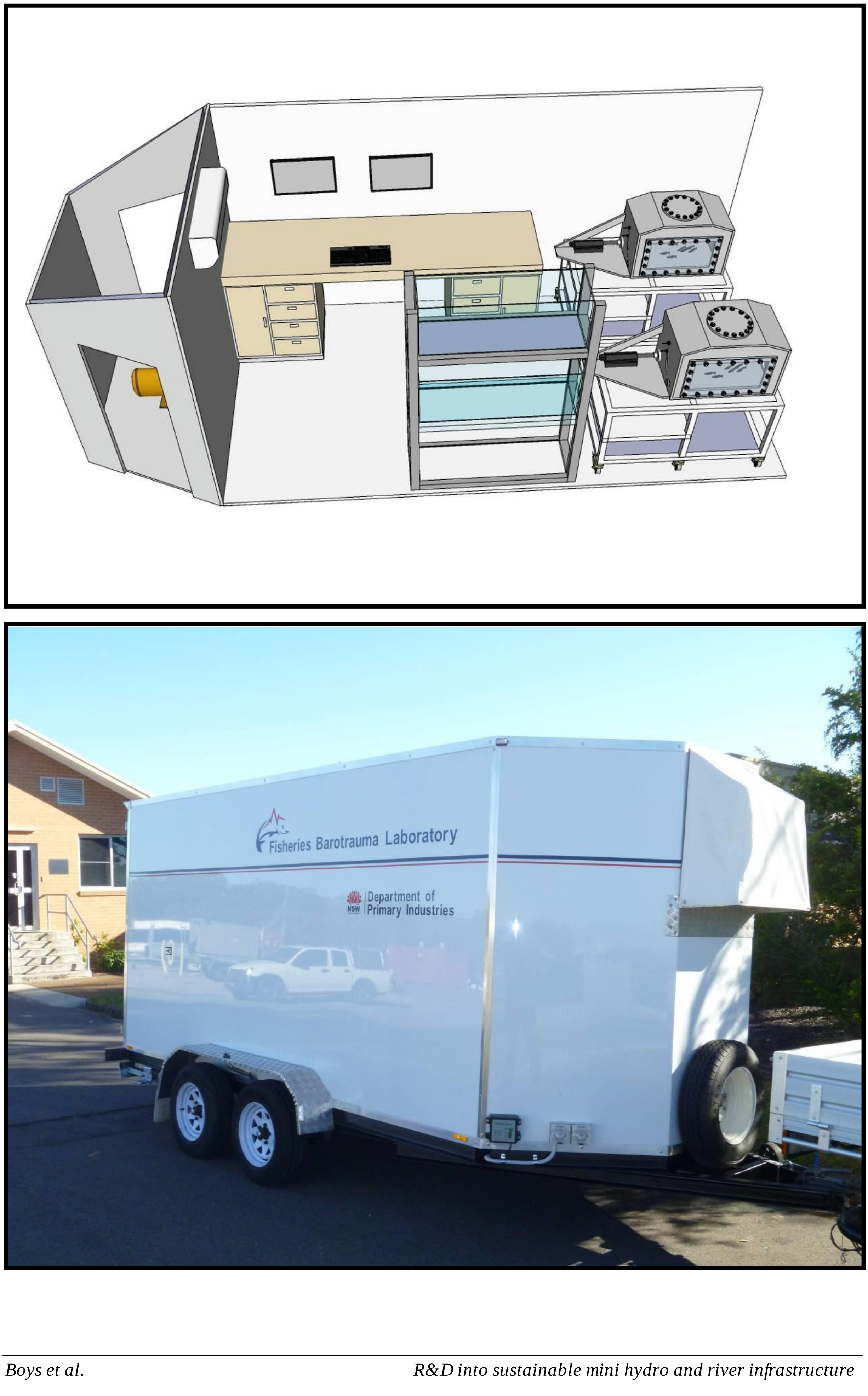


Figure 20. Mobile barotrauma laboratory trailer



4.1.1. Overview of operation

The chambers operate in a manner similar to that documented in Stephenson *et al.* (2010). The stepwise process is run on a Labview software interface under the control of the user. In summary this is as follows:

1. The user directs the software to an acclimation file (.csv) and a trauma file (.csv) that determines the pressure profile that fish will be acclimated at and the level of decompression that the fish will be exposed to during the trauma phases.
2. The user-defined control software opens the inlet valve, closes the outlet valve, starts the pump to fill the tank then closes the inlet valve.
3. The user removes the lid, inserts the fish and reseals the lid.
4. The software starts the pump, and gradually (over a period of one to two minutes) adjusts the inlet and outlet valve so the desired pressure (as per the pre-programmed acclimation input file) is being monitored on the pressure transducers. The pressure can then be increased over many hours to slowly acclimate the fish to a desired pressure and simulated depth. The pressure profile during acclimation is displayed on the screen and logged to an output file.
5. With the pump continuing to circulate water, the control software will continually monitor and log the pressure in the tank (making subtle adjustments to the outlet valve) throughout the acclimatisation process.
6. If an air pocket was maintained at the top of the tank for the acclimation of physostomous species, this is now removed by opening an air bleed valve on the top of the tank and gradually (over a period of one to two minutes) the air is purged from the chamber.
7. The operator must then manually close both inlet and outlet ball valves and turn off the pump, leaving the barotrauma chamber sealed for the start of the test. Eventually this process will be automated by either spring-loaded ball valves and/or solenoid valves under software control.
8. The control software runs the pre-programmed trauma file while logging pressures at 20 Hz. This involves the actuated rod being pulled out of the chamber.
9. Csv files containing data of the programmed and actual pressure profiles achieved during the acclimation and trauma phases are saved to a predefined location on the computer.
10. The control software then opens the outlet valve to ensure the chamber is no longer pressurised.
11. The user opens the lid and removes the fish

4.1.1. Commissioning and range testing

Initial range testing was performed on the chambers during both the acclimation and trauma phases. The chambers successfully maintained pressures at 250 kPa (15 m depth) absolute during the acclimation phase. A variety of trauma files were tested, ranging from a lower ratio pressure change (RPC) of 1.28 [ln(RPc) of 0.25] through to a maximum RPC of 20 [ln(RPC) of 3]. The chambers responded as required (Figure 21) and reached the desired nadir pressures with sufficient accuracy to suggest that the desired range of RPC's will be able to be reliably generated during mortality experiments (Table 4). Because very low negative pressures (nadir 10 kPa) can be generated in the chamber, it was possible to achieve RPC's of up to 10 [ln(RPC)=2.25] from acclimation pressures equivalent to surface pressure (100 kPa) (Figure 21 and Table 4). This is desirable because it will reduce the need to acclimate experimental fish to greater depths/pressures during the experiments, therefore reducing experimental time and increasing the capacity to run a greater number of treatments and/or replicates. RPCs between 10 and 20 could only be achieved by acclimating at higher pressures. In this case, RPC's between 10 and 20 were achieved from an acclimation pressure of 200kPa (approximately 10 m depth). The RPCs could be generated in as low as 0.2 second (for lower RPCs), with the highest ratio (around 20) achieved in 0.5 second (Table 4).

Figure 21. Trauma output plot showing a range of trial decompressions tested ranging from a log ratio pressure change 0.25-3.0 (RPC 1.2-20.0) (continued over page). The red line shows the pressure profile pre-programmed into Labview and the blue line shows the pressures actually achieved. Statistics concerning the ranges achieved are presented in Table 4.

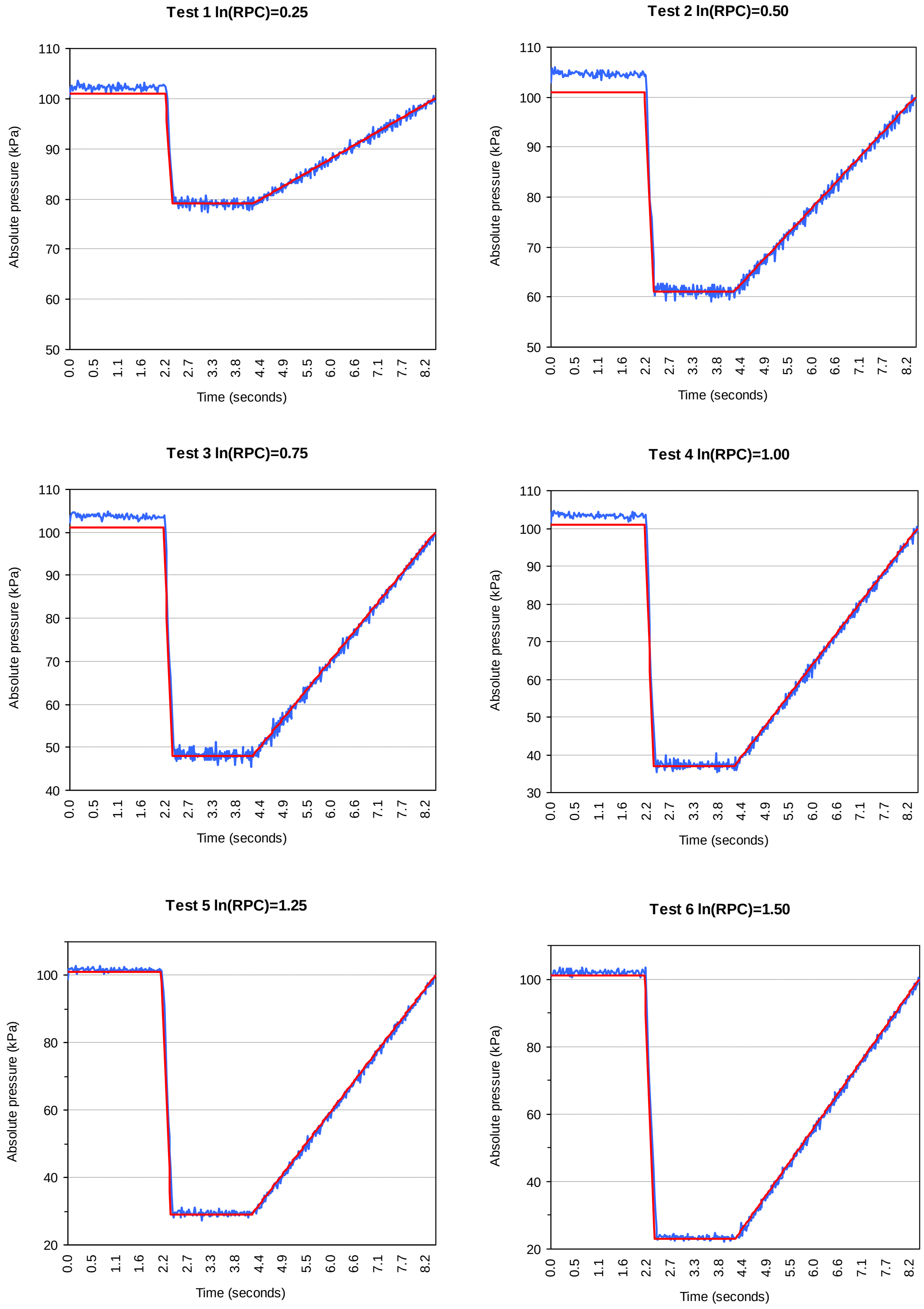


Figure 21. (continued from previous page).

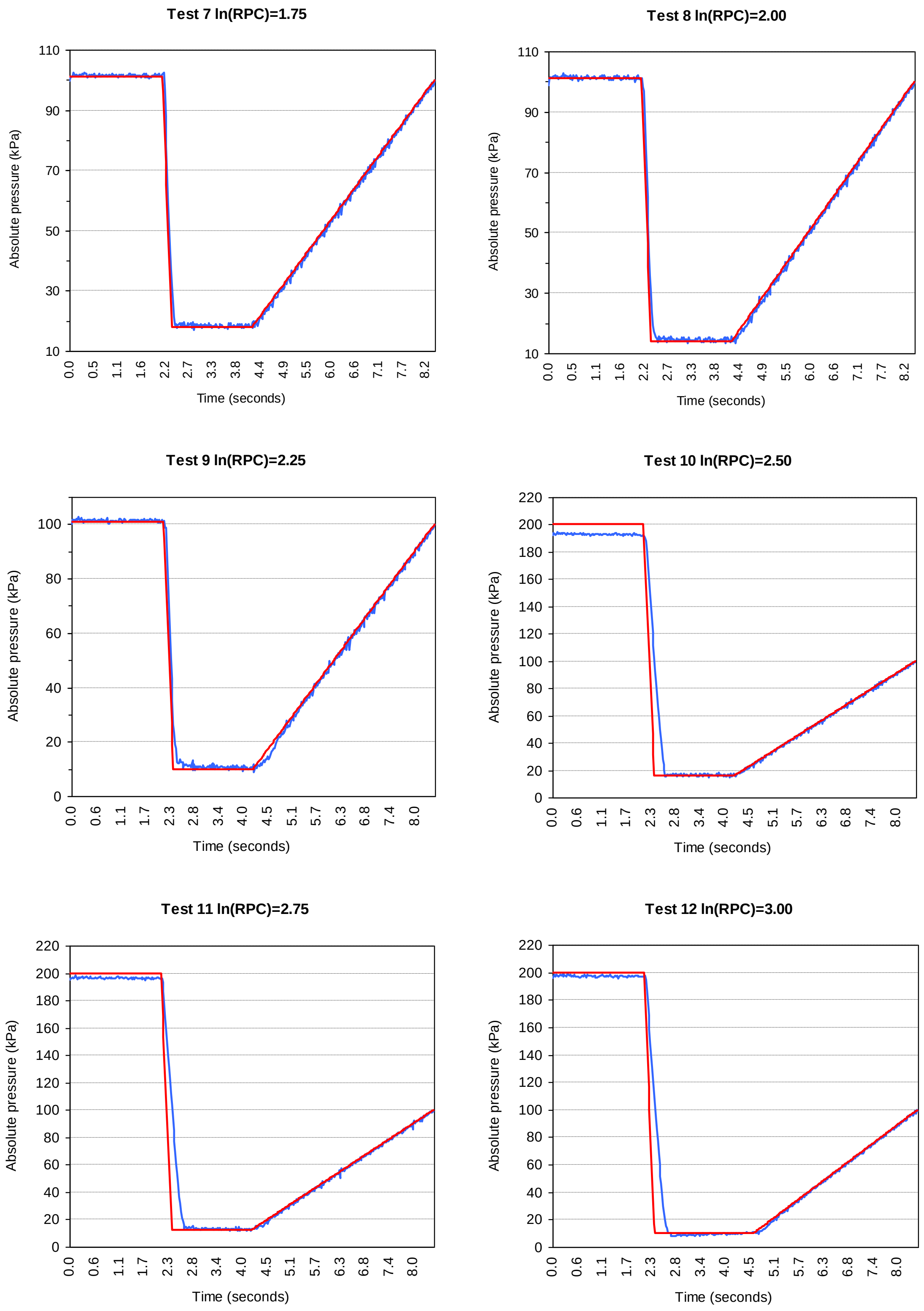


Table 4. Summary statistics from barotrauma chamber range testing for 12 pre-programmed ratio pressure changes. Shaded columns show the desired (left) versus achieved (right) ratio pressure changes (RPC).

		Pre-programmed				Observed					
Test	Acclimated (kPa)	Nadir (kPa)	Time (sec)	RPC	ln (RPC)	Nadir (kPa)	Time (sec)	Pressure change (kPa)	RPC	ln (RPC)	Rate (kPa/sec)
1	101	79	0.25	1.28	0.25	79.08	0.2	21.92	1.28	0.24	109.60
2	101	61	0.25	1.65	0.50	61.2	0.3	39.8	1.65	0.50	132.67
3	101	48	0.25	2.12	0.75	48.2	0.3	52.8	2.10	0.74	176.00
4	101	37	0.25	2.72	1.00	37.23	0.3	63.77	2.71	1.00	212.57
5	101	29	0.25	3.49	1.25	27.31	0.3	73.69	3.70	1.31	245.63
6	101	23	0.25	4.48	1.50	23.36	0.3	77.64	4.32	1.46	258.80
7	101	18	0.25	5.75	1.75	18.37	0.4	82.63	5.50	1.70	206.58
8	101	14	0.25	7.39	2.00	14.54	0.3	86.46	6.95	1.94	288.20
9	101	11	0.25	9.49	2.25	10.71	0.4	90.29	9.43	2.24	225.73
10	200	16	0.25	12.18	2.50	16.36	0.5	183.64	12.22	2.50	367.28
11	200	13	0.25	15.64	2.75	13.06	0.5	186.94	15.31	2.73	373.88
12	200	10	0.25	20.09	3.00	8.65	0.5	191.35	23.12	3.14	382.70

All pressures in absolute.

4.2 Shear flume

4.2.1. Design specifications and operation

Shear tests require that fish be exposed to a standard, quantified shear environment. A shear flume has been constructed and tested by the WRL (Figure 22). Key design specifications include:

1. The shear environment is created in a transparent cylindrical chamber, 0.44 m in diameter, where a high-velocity submerged jet will produce the desired flow environment (Figure 23a).
2. One end of the flume has a reservoir from which water is pumped to the opposite end of the flume through a submerged nozzle (Figure 23b).
3. Water is pumped through 0.15 m PVC pressure pipe.
4. An in-line rotameter (Wollman Turbo) is used for measurement of the flow rate.
5. An electric Grundfos NBG 125-100-315/279 3-phase electric pump is used to generate the desired flow conditions of up to 20 m/s nozzle exit velocities.
6. The submerged jet is created by a customised nozzle, 0.15 m in diameter constricting to a circular 0.05 m diameter over 0.26 m in length (Figure 23c).
7. A deployment tube for the test species is set at an angle between 30 - 45° angle to the edge of the jet, and will introduce the fish immediately above the jet stream and in front of the nozzle.
8. High-speed video footage can be used to record the behaviour of the test fish in relation to the shear jet.

4.2.1. Commissioning and range testing

WRL collected velocity measurements across the jet profile within the shear flume 90 mm from the nozzle at 5 mm points extending from the jet centreline (Figure 24). Velocity heads were determined using a total tube with a calibrated pressure gauge attached to it. The pressure gauge could record a pressure range of 0 – 250 kPa to an accuracy of 5 kPa. The measured velocities, as shown in Table 5 and Figure 25, were calculated by simply converting the velocity head (m) measured using the total tube to a velocity (m/s) through use of the Bernoulli equation:

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

Where *H = Total Head (m)*
v = Velocity (m/s)
g = Gravitational Constant (m^2*/s)*

The theoretical velocities for various flows through the nozzle were calculated by assuming no loss from the flow meter to the nozzle. An additional 0.52 m of pressure head was measured during testing based on the elevation read from the manometer board.

The preliminary results demonstrate that the most active area for shear is at the point between 20 and 30 mm from the centreline (Figure 25), and fish should be introduced at this point. For example, a fish introduced with the tip of the deployment tube positioned 20 mm from the centreline at a flow rate of 20 L/sec, would experience differences in velocity between 11 m/sec and 6.3 m/sec in the first 10 mm (or body length of a juvenile fish) (Table 5). Work is underway at Narrandera Fisheries Centre to calibrate strain rates from this velocity profile prior to shear testing.

Figure 22. Overview of shear flume

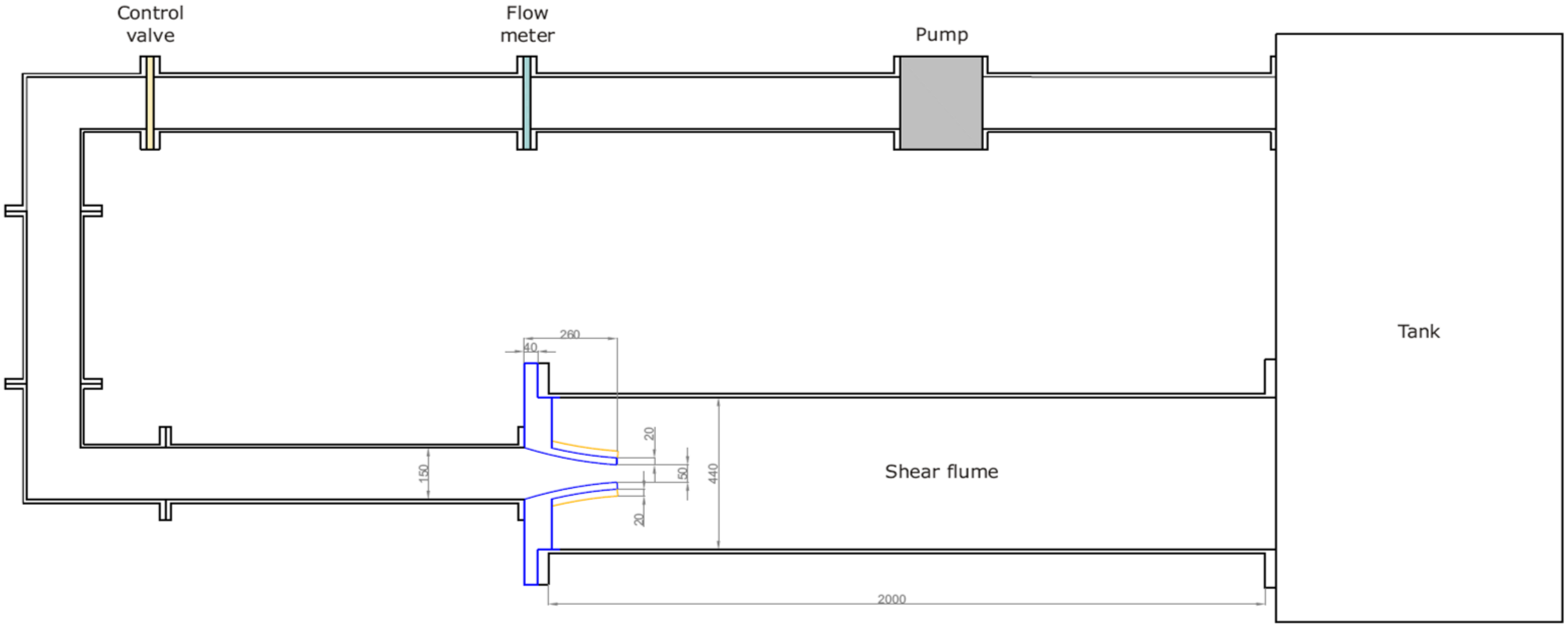
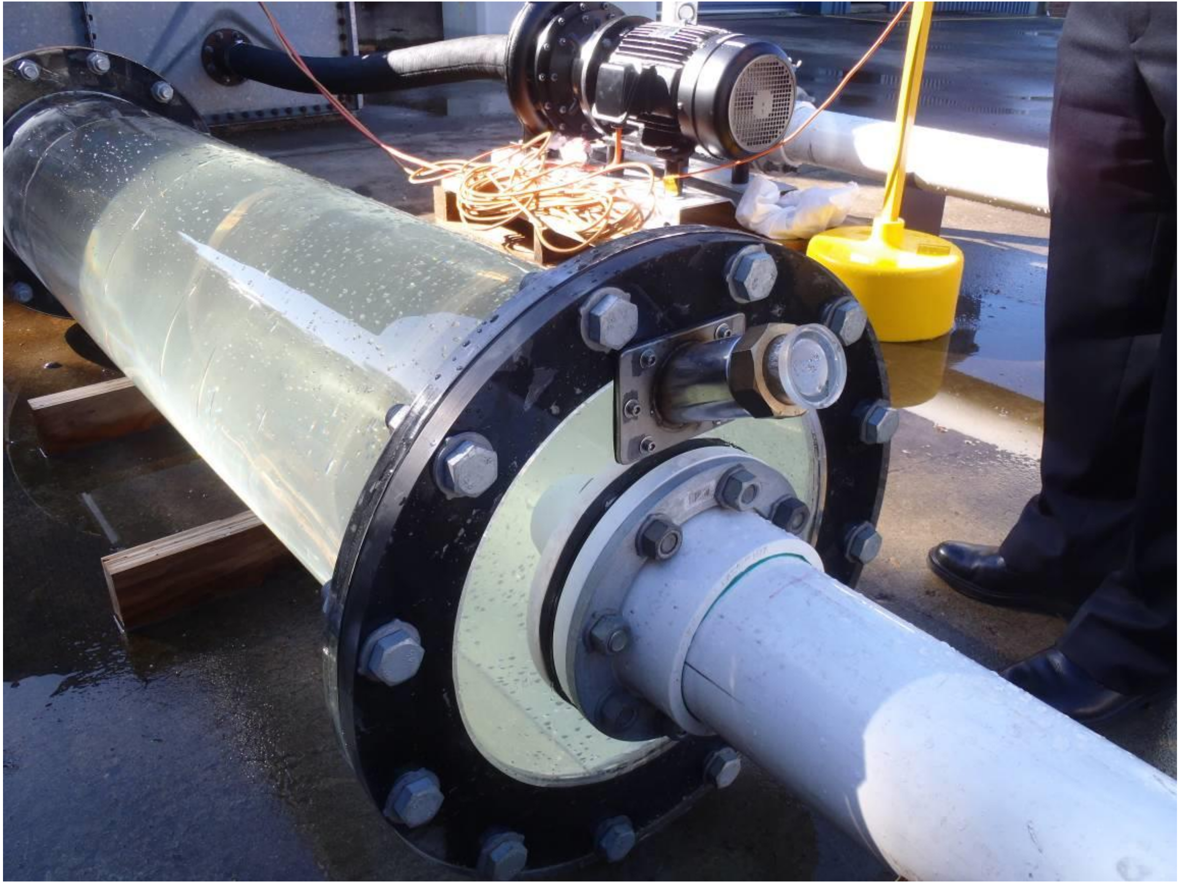


Figure 23. Photos of the main components of the shear flume (continued over page).

a) Flume



b) Nozzle for creating jet stream

c) Grundfos NBG 125-100-315/279 3 phase pump

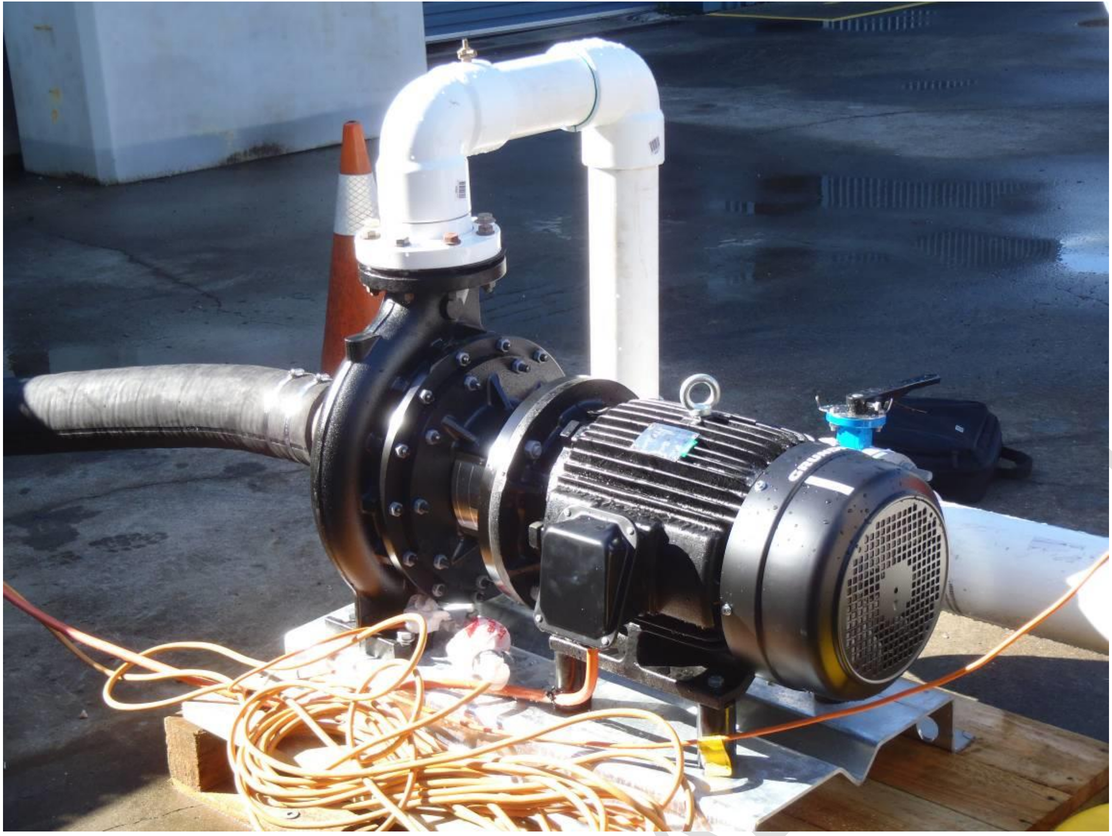


Table 5. Velocity measurements (m/sec) across the jet profile (distance from centreline) for given flow rates (L/sec) in the flume.

Measured Velocity (m/sec)	**Flow (L/sec)**							
Distance from Jet Centreline (mm)	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**37**
0	4.7	6.3	8.7	11.0	13.6	16.1	18.7	19.7
5	4.7	6.3	8.7	11.0	13.6	16.1	18.7	19.7
10	4.7	6.3	8.7	11.0	13.6	16.1	18.7	19.7
15	4.7	6.3	8.7	11.0	13.6	16.1	18.7	19.7
20	4.7	6.3	8.7	11.0	13.6	16.1	18.7	19.7
25	4.2	5.5	7.7	10.0	11.8	14.1	16.7	18.4
30	3.7	4.7	5.5	6.3	7.7	8.4	10.5	11.0
35	3.7	4.0	4.0	4.2	4.5	5.3	5.5	6.0
40	3.2	3.7	3.2	3.2	3.2	3.2	3.2	3.2
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Theoretical Velocity at Centreline (m/sec)	2.5	5.1	7.6	10.2	12.7	15.3	17.8	18.8

Figure 24. Flow establishment zone within the flume, the location of the velocity measurements taken relative to the nozzle and fish deployment tube.

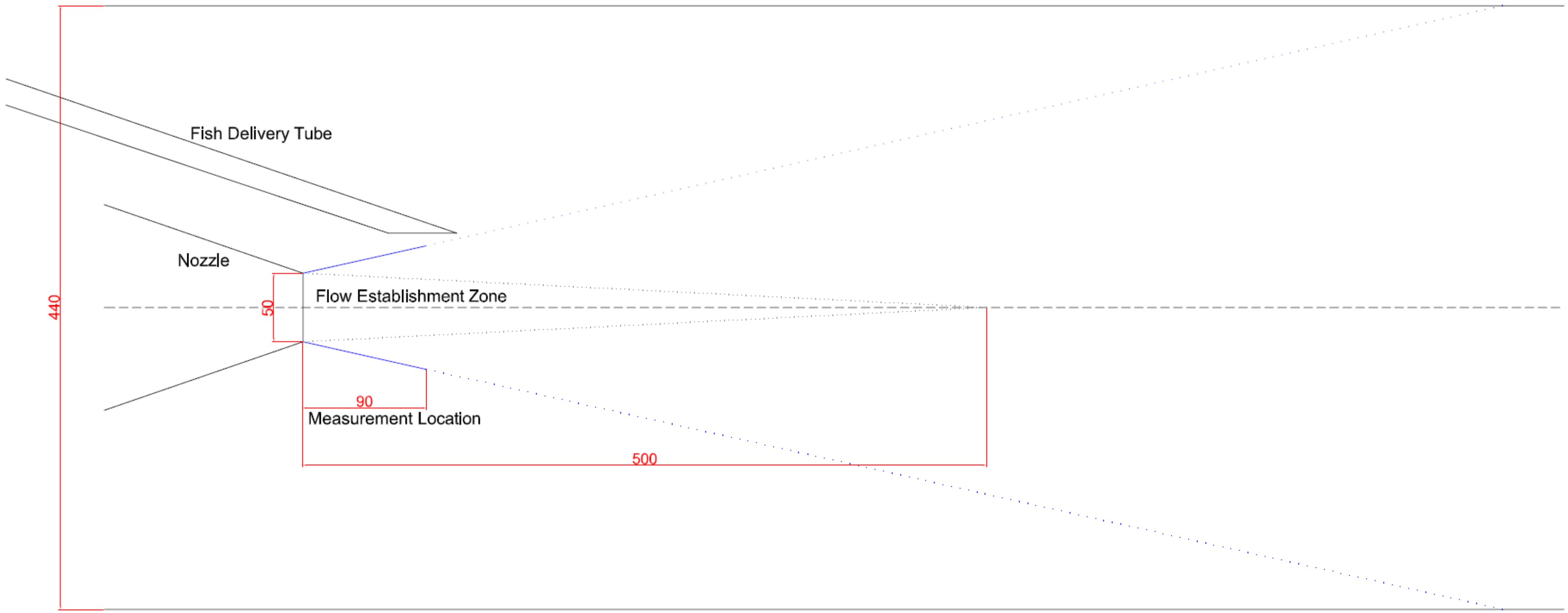
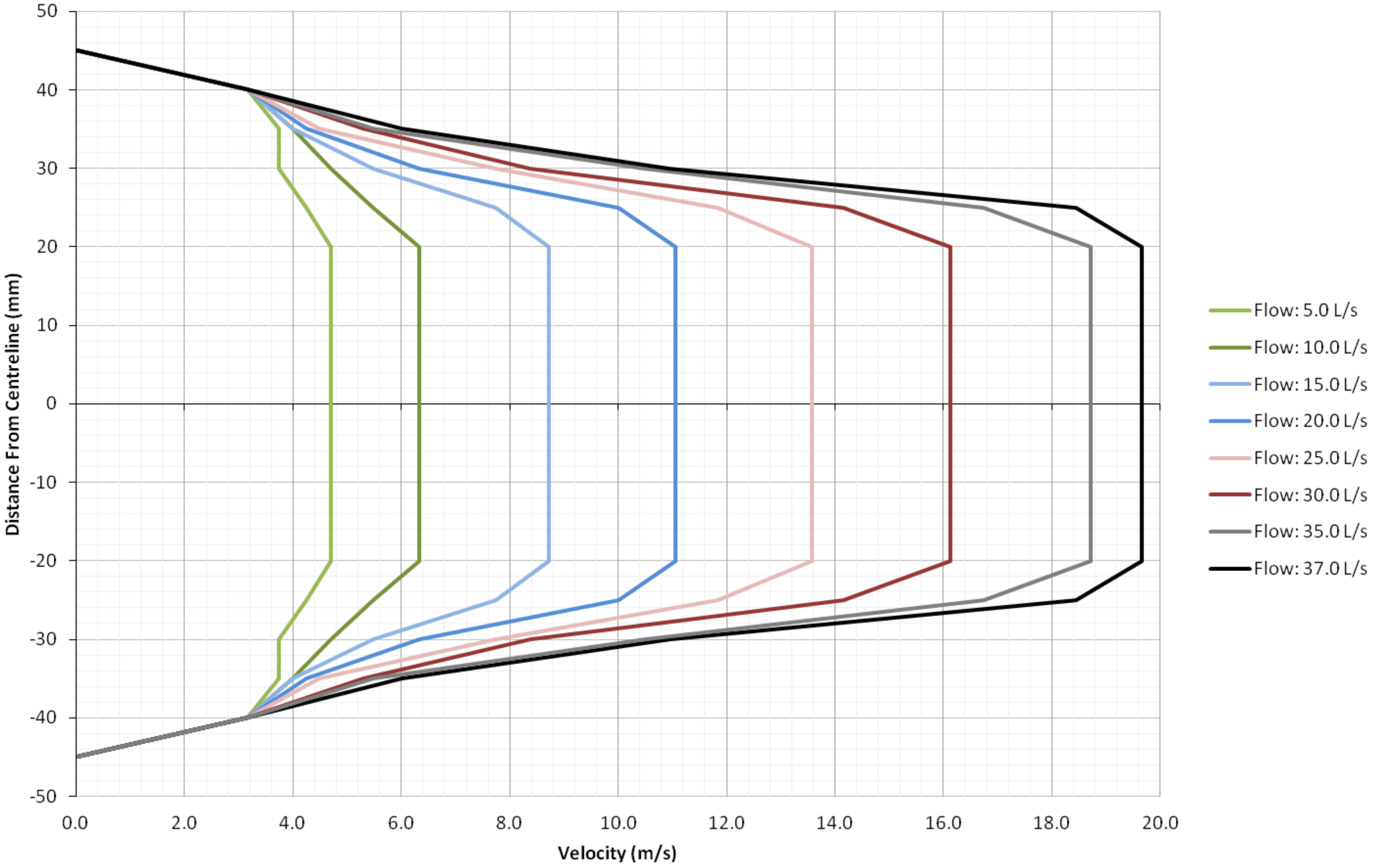


Figure 25. Velocity measurements (m/sec) across the jet profile (distance from centreline) for given flow rates (L/sec) in the flume.



5. EXPERIMENTAL DESIGN AND LABORATORY PROCEDURES FOR BAROTRAUMA AND SHEAR EXPERIMENTS

5.1 Barotrauma experiments

5.1.1. Factors to be investigated

Two specially-designed barometric chambers (see Chapter 4) will be used to simulate the rapid decompression that occurs to fish as they pass weir and hydropower infrastructure. The procedures will be based upon the experiments and facilities outlined in Stephenson *et al.* (2010) and Brown *et al.* (2012a), and will attempt to model the relationship between the ratio pressure change experienced during passage and injury or mortality.

The depth and pressure at which a fish is acclimated at prior to infrastructure passage is a critical factor dictating its susceptibility to barotrauma. This is because the ratio of pressure change between the pressure a fish is acclimated at and the nadir (lowest) pressure a fish is exposed to during passage will dictate the magnitude of expansion in gas volume within the swim bladder. This is governed by Boyle's Law, where $P_1 x V_2 = P_2 x V_2$. That is, for every 50% reduction in pressure, there is a doubling in gas volume. It is this ratio of pressure change that therefore dictates the level of swim bladder expansion and has been shown to be significantly correlated with injury in fish during simulated passage hydroturbines turbines (Brown *et al.* 2012b).

Determining which ratios to test requires some knowledge of the depths different species are acclimated at prior to passage and the nadir they will be exposed to. There is no information available on the depths at which Australian freshwater fish are typically acclimated to when migrating downstream. Additionally, little is known of the exposure pressures of existing hydropower facilities in Australia and it is not possible to assume what pressures may be expected from future hydropower technologies. Therefore, it is prudent that any laboratory testing be done to encompass a large range of ratio pressure changes, which will allow flexibility in determining the likely impact from a wide range of technologies and also enable information on the migration ecology of species to be incorporated into mortality models as it comes to hand.

When deciding what nadir pressures and ratio of pressure changes to test in laboratory trials, a number of factors have been considered (Table 6):

1. The nadir pressure modelled and measured at undershot weirs;
2. The maximum nadir pressures modelled for a low-head hydropower facility (the hydroEngine™);
3. Published information on the maximum nadir pressures measured at a high-head hydropower facility;
4. Published information on thresholds of nadir and ratio of pressure change resulting in mortality of other species;
5. The nadirs and pressure falls that can be feasibly simulated in the lab; and
6. The rate of pressure change for all of the above.

CFD results have been obtained for one type of mini hydropower technology, the hydroEngine™ (Natel Energy, unpublished data). The hydroEngine™ operates by transferring energy from falling water impacting a series of horizontal blades to a power train that rotates around an upper and lower shaft. CFD modelling (ANSYS Fluent) was undertaken of pressure changes through the hydroEngine™ when operated at 5.4 m of head (which is most comparable to the 8 m weir pool CFD scenarios and the Sensor Fish releases conducted at Hay weir). CFD modelling suggests that a significant proportion of the flow through the hydroEngine™ does not fall below 100 kPa (surface pressure), with some small areas on the leading edge of blades and the downstream edge of louvres generating pressures of 83.9 kPa. A nadir of 49.9 kPa was predicted to occur on the downstream row of louvres and the leading edge of the downstream row of blade. Although exposure to such extreme nadir pressures may be rare, it must be considered possible at this stage. Further CFD modelling or Sensor Fish trials at a pilot facility would confirm the probability of these extreme exposure pressures and also provide an indication of the rate of pressure change.

To properly model the association between ratio pressure change and mortality, it is advisable to subject fish to a range of ratios up to the point that induces 100% mortality. Brown *et al.* (2012) showed that ratios of 18.2 induced 100% mortality in juvenile Chinook salmon. Such ratios will be possible with the newly constructed chambers which can achieve pressure drops from 200 kPa to 10 kPa (a ratio pressure change of 20). It is therefore assumed that ratios up to 20 will encompass most if not all of the variation in mortality in Australian species, and also encompass the likely range of acclimation pressures (dictated by migratory behaviour) and exposure pressures faced by fish at any weir, dam or hydropower facilities (Table 6).

Table 6. Extreme nadirs and ratio of pressure change (acclimation to nadir pressures) that should be allowed for in laboratory testing based on various sources of information.

Source	Nadir pressure	Ratio of pressure change and (rate)	Notes
Hay weir	95 kPa	1.9 (0.25 seconds).	180 kPa (8m) acclimation to nadir.
* hydroEngine™	50-100 kPa	1.8-3.6 (rate unknown).	180 kPa (8m) to nadir shown in CFD modelling (Natel unpublished data).
High-head hydropower facility	24 kPa	8.3 < 1 second).	Kaplan turbine (R. Brown pers comm.). Ratio assumes benthic acclimated fish (10 m) at structure such as Yarrawonga Dam.
Mortality models	NA	9 (< 1 second) → 95% mortal injury 18 (< 1 second) → 100% mortal injury.	Based on juvenile Chinook salmon (Brown *et al.* 2012a)
Capable of simulation in the test facilities	10 kPa	20 (in 0.5 seconds). Faster rates (0.2 seconds) are possible for ratios below 10.	Based on chamber testing.

* The hydroEngine™ was used as a case study mini hydropower facility (see glossary).

5.1.2. Juvenile fish

Ten fish (per chamber) will be randomly dip-netted from holding tanks and transferred in a small bucket and placed in each of the two barometric chambers. Fish will be acclimated to the desired pressure whilst water continuously flows through the chambers to maintain oxygen levels within each vessel. A video system will monitor fish behaviour during the acclimation period. It may take fish as long as 24 to 48 hours to achieve neutral buoyancy when acclimated at pressures greater than surface pressure. Neutral buoyancy will need to be assessed for depth acclimated fish by observing the swimming behaviour of individual fish. Any fish not judged to have achieved neutral buoyancy prior to decompression must be disregarded from analysis. This will require that some identification system be in place (e.g. fin-clipping or marking) to enable individual fish to be identified prior to and after experimentation.

After the acclimation period is completed, the fish will be subjected to simulated infrastructure passage (SIP) consisting of one of 13 pre-programmed ratio pressure changes ranging from zero through to 20 [ln(RPC) 1 to 3] (Table 7). The SIP phase will consist of rapid decompression over a quarter to half a second. Following SIP, fish will be slowly brought back to atmospheric pressure and removed from the chambers and transferred into nearby observation tanks. Fish showing signs of injury or mortality will be euthanased immediately and dissected to ascertain the nature of any internal injuries. All other fish will be allowed 24 hours to recover. At this time all fish will be euthanased and dissected. Types of injuries will be recorded (e.g. swim bladder rupture, haemorrhage, exopthalmia, or gas bubbles in organs). Logistic models will be generated of the rate of mortality or different injuries and ratio pressure change.

Table 7. Thirteen treatments to be examined during simulated infrastructure passage to generate a logistic model between injury/mortality and ratio pressure change.

	Absolute pressure (kPa)			
Treatment	Acclimated	Nadir	RPC	ln (RPC)
A	101	101	1.00	0.00
B	101	79	1.28	0.25
C	101	61	1.65	0.50
D	101	48	2.12	0.75
E	101	37	2.72	1.00
F	101	29	3.49	1.25
G	101	23	4.48	1.50
H	101	18	5.75	1.75
I	101	14	7.39	2.00
J	101	11	9.49	2.25
K	200	16	12.18	2.50
L	200	13	15.64	2.75
M	200	10	20.09	3.00

5.1.3. Fish larvae and eggs

Larval fish of some species will be examined for swim bladder inflation and susceptibility to barotrauma every two days from the first day of hatching. This will involve placing 10 larvae into a chamber and subjecting them to a RPC of 5 (120 to 24 Kpa) over two seconds and then returning them to 120 kPa. Swim bladder inflation will be determined as a change in buoyancy during decompression. Larvae will then be examined for mortality within a few hours and at 24 hours. Any fish dead at zero of 24 hours will be examined under a microscope for injury, as will all fish once euthanased after 24 hours. Once larvae start to show evidence of swim bladder inflation (buoyancy change) or injury from decompression, that age group will be subjected to the full range of ratio pressure changes as for juvenile fish (with the exception of RPC's above 10) (Table 7) and examined for injury. Fertilised eggs of some species (e.g. silver perch and golden perch, which have a drifting egg stage) will be subjected to the 13 SIP treatments listed in Table 7. Each replicate group will be subsequently be observed for mortality and healthy hatching.

5.2 Shear experiments

High values of fluid shear occur where water rapidly passages through river infrastructure, including through undershot weir gates and through hydro turbines. The effects of shear on fish passing infrastructure is poorly understood, but has been investigated to some degree on migrating salmon smolt and has been shown to cause some injury. Ideally, fluid shear and turbulence could be reduced through operational or design modifications to both existing and proposed infrastructure. To achieve this we need to better understand the lethal and sub-lethal thresholds of shear on fish. In this experiment we will expose fish to a laboratory-generated shear environment using a high-velocity jet into a swimming flume.

5.2.1. Main experiment

A flume (Chapter 4) fitted with a submerged jet (from a variable speed pump) will to be used to generate different velocities which will enable fish to be subjected to different strain rates. Individual fish will be taken from holding tanks in a small transfer tube and introduced via a small deployment tube, into a known shear environment. Fish will be taken from exposed to 1 of 6 different strain rates (cm/s/cm). Juvenile fish will be tested in two orientations; head first and tail first (as per Neitzel *et al.* 2004). Orientation will not be tested for larval fish and egg. Following exposure, fish will be captured from the flume using a dip net or larval net. Potential handling effects will be determined by releasing fish through the deployment tube without the pump running. Test fish will be held for up to 48 hours post experiment in adjacent holding cages to assess the type and extent of injuries (e.g. de-scaling, haemorrhaged, isthmus tears, eye damage) and direct mortality (initial and delayed).

Logistic regression will be used to analyse the effect of strain rate on injury and mortality levels for various species/age class runs and for different deployment orientations. Odds ratios will be used to determine the proportional reduction in mortality/injury that can be achieved from each drop in strain rate. For juvenile fish, six strain rates (plus one control) and two orientations will be tested (7x2=14 treatments), with 30 fish tested per treatment = 420 fish. For eggs and larval fish six strain rates (plus control = seven) will be tested (with no orientation). Using 30 fish per treatment, this equates to 210 eggs and larvae of each species.

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APPENDIX 1 – PROCEEDINGS OF RESEARCH DEVELOPMENT WORKSHOP

Prepared by Roy Barton Australian Centre for Value Management Pty Ltd

NSW Government

Department of Trade and Investment

Mini Hydro Systems

Research Workshop Report

10 October, 2011

The Australian Centre for Value Management Pty Ltd
(ACVM)

CONTENTS

1. INTRODUCTION

1.1 Purpose of the workshop

The purpose of the workshop was to seek agreement amongst the consent authorities, researchers and development-companies, as to *the requirements that must be met to enable the development and initiation of a research program* that will guide the widespread application of fish-friendly, mini-hydro facilities in NSW.

1.2 Context of the workshop

There is presently a paucity of information available on the likely response of fish to mini hydro systems, particularly in Australia (and for Australian fish). This results in a significant deterrent to the use of mini hydro in Australia, particularly in obtaining approval for such schemes from consent authorities.

It is known that most adverse impacts from hydro schemes arise from the use of large turbines at high head installations where fish are damaged by sudden pressure changes, physical strike with turbine blades and damage from fluid shear. USA researchers have done a substantial amount of work determining critical thresholds of these to minimise impacts on fish and turbines are now constructed to that criteria. These factors are more significant at high head installations but there are now a range of mini hydro systems that can generate substantial amounts of power from low operating heads and have reduced environmental impacts.

Several mini hydro designs are ready for direct application but consent but has not yet been granted for two reasons. Firstly, a detailed development application for installation of a system is yet to be submitted. Secondly, consent agencies would like additional information from evidence-based research results concerning environmental impacts of this technology.

Consequently, this workshop was convened to bring together representatives of consent authorities, researchers and development companies to seek agreement as to the requirements that must be met to enable the development and initiation of a research program.

1.3 Proceedings

The workshop was opened by The Hon. Rob Stokes, MP, Parliamentary Secretary for Renewable Resources. Mr Stokes welcomed everyone to the workshop, especially the overseas participants, and stressed the importance of the exercise to New South Wales. He described mini hydro schemes as a mature technology that provided many opportunities that could be exploited immediately. In particular, Mr Stokes referred to the recent example of a mini hydro system that has been attached to Prospect reservoir.

The workshop followed a structured agenda that is included in appendix B. After the official opening and some preliminary items, the workshop proceeded through a number of discrete phases beginning with a time of building shared knowledge and understanding amongst all participants of the breadth and depth of the issues facing mini hydro research, operations and approval processes.

In setting the scene for all this, Dr Lee Baumgartner explained that there is currently conflict and confusion concerning the burden of proof for the safety and efficacy of mini hydro systems and hence the need to establish exactly what is required in terms of research evidence so that consent can be forthcoming. He further explained that we could have green technology that will help build rural industries and grow rural economies in an ecologically sustainable manner and that each weir is a potential hydro plant. He emphasised that, from the consent authority perspective, the job is to enforce legislation to protect biodiversity, given the chequered past of hydropower. Proponents may therefore need to prove that projects will not have a significant impact. Dr Baumgartner said that we need to consider such things as:

- Fisheries Management Act 1994 (particularly section 218/219)
- EPBC Act (particularly for threatened species)
- Environmental Planning and Assessment Act
- State listings of endangered ecological communities
- Presence of threatened species
- Potential for significant impacts?

He concluded with the question: *"Can we provide data that can inform the decision making process for the mutual benefit of developers and consent authorities?"* This research question became the focus of activity later in the workshop.

The scene-setting presentation was followed by workshop activity where the group, collectively, put forward their points of view in relation to the primary purposes of mini hydro, the expected benefits from such schemes and, the characteristics or features of mini hydro schemes that are of particular importance or significance (See Part 3 of this report)

After this, a number of PowerPoint presentations were given, followed by questions and answers:

• Proposed mini hydro development in Australia	Andrew Jones
• Welfare of fish during downstream passage	Lee Baumgartner
• Development applications and consent process in NSW	Angus Northey and Sarah Fairfull

Copies of these presentations may be obtained from Dr Lee Baumgartner (see appendix A for contact details).

The workshop then shifted focus, from building shared knowledge and understanding, to developing proposals (which was done in focus groups). We then proceeded to evaluate the proposals and make recommendations, leading to closure of the workshop at 4.45 pm. All of the material produced in the workshop was then taken and used over the next four days by a group of participants who returned to Narrandera to continue discussion and development of a framework for research activities.

2. RECOMMENDATIONS

2.1. Research requirements for mini Hydro

Pre-construction

Field-based investigations

- Sensor Fish trials – quantify baseline pressure / shear / velocity etc.
- Compare: Undershot / overshot / proposed hydro / natural river channel.
- Investigate 'real world' actual mortality at undershot gates and quantify the proportion of the population that actually pass downstream through structures.
- Perform combined Sensor Fish/live-fish studies with different release depths to determine potential factors influencing welfare.
- What fish are located at the study site? Which of those may be impacted?* Consider a well-designed before/after study to look into potential benefits/impacts post construction.
- We need to consider lethal and sub lethal effects.
- Would be useful to prepare a GIS-based map of potential mini hydro sites throughout NSW and draw on existing outcomes of NSW weir review

Lab-based investigations

- Barotrauma work: What are the critical tolerances for fish? At what life history stage? – rate of change important
- Shear flume: What are critical values of shear? Does this differ among species and life stages?
- Develop fish-movement information to categorise/prioritise risk to species in the region. (Desktop study)

Additional knowledge needs:

- What level of mortality is acceptable?
- What is the maximum height of a barrier that small hydro can be fitted?
- What percentage of the population must be passed to sustain existing populations?
- Need to establish performance standards for operation.

Post-construction

Pursue the following items to develop further knowledge and understanding – they are not essential requirements for initiating and developing the research program

Field-based investigations

- Consent authorities to define acceptable biological performance standards including an acceptable level of mortality at both the site and reach scale
- Is the hydro plant meeting biological performance standards?
- Is the plant improving the situation / is it better than undershot weirs? Is the fish community recovering as expected? Is it better than a rehabilitated/removed structure? (i.e. Overshot weir)
- Sensor Fish: Do actual hydraulic conditions meet expected conditions (first site only)
- Blade strike: What are expected losses of fish through blade strike? What species are susceptible?
- Continue before / after work.

2.2. Policy regarding mini hydro

- We need fundamental, independent, reductionist, research to inform general mechanisms injury, mortality, survival. This will enable preliminary guidelines to be produced for developers/regulators.
- At a project proposal stage have some evidence of hydraulic performance of technology and how it compares to status quo at site.
- Site by site basis for consideration rather than technology by technology basis.
- Pilot trial evidence carries more weight than modelled data
- Focus on protect most vulnerable life stages
- What are reasonable offsets?

2.3. Construction requirements for mini hydro

Create regulatory environmental management certainty (i.e. provision of benchmarks of acceptable impacts, sufficiency of experimental data/methods/processes, definition of 'significance').

- *Research/Pilot/Policy – a circular, but adaptive, feedback loop*
- *Expert panel approach*
- *Produce a flow-chart bridging science/policy*
- *Note: This can proceed in parallel with the research*

Development agencies require less subjectivity in environmental assessment requirements and need to engage researchers/regulators in environmental assessment proposals at an early stage in order to provide greater levels of guidance.

Consent authorities should actively engage with proponents during the design and development application phase. Most developers want to ensure design and construction complies with biological requirements and early engagement is needed to clearly define and meet any expectations.
Note: This should precede, and help to inform any subsequent research program, but it is imperative that regulators help to inform, rather than resist, the process

Need to ensure greater available experimental (fish impact) data that is widely-available available to industry and accepted by regulators (i.e. lack of baseline data from impacts from existing weirs).
Note: this will be a research outcome

Ability to extrapolate data from other experimental impact research for use in mini hydro applications.
Note: this will be a research outcome

Greater facilitation/funding/in-kind research provided by regulators.
Note: this will be a research outcome

2.4 Risks with mini hydro

During proceedings, the matter of risks relating to mini hydro schemes was raised. Consequently, a focus group was set up to identify the "high level" risks. This was not intended to be a formal risk study, simply an exercise to capture the "high level" risks to add to the knowledge and understanding of the group. The risks that the group identified are listed below. Upon reflection by the whole group, it was concluded that none of these risks are "show-stoppers" initially, but research after construction may provide adaptive feedback into the development of mini hydro at other sites. The list was placed on record for further consideration as research and development continues.

ECOLOGICAL RISKS:

- Potential impacts on fish, turtles and other aquatic life
- Sedimentation
- Changing of hydrology – flows seasonality etc.
- May improve passage of some invasive species?
- Change of attraction flows location
- Decreased future rehabilitation likelihood
- Potential to influence e-flow delivery
- Generator infrastructure effects on terrestrial species
- Changes in fish behaviour (reluctance to enter openings or dark places)
- Changes in fish community composition
- Interruptions at different stages of the life cycle
- Potential for promotion of downstream passage only
- Not detecting change

CONSTRUCTION RISKS:

- Operational risks – lack of water/flow

- Accessibility
- Permits
- Access to the grid
- OH&S
- Flooding, loss of capital outlay.
- Delays
- Geotechnical conditions
- Site regulatory requirements, e.g. burials etc.
- Costs of works (e.g. bunting)
- Timing (of construction)
- Loss of demand
- Community backlash – (perception of wasting water by sending it downstream)
- Potential to modify weir operations may trigger fishway requirements
- Climate change
- Carbon offset
- Other renewable options become cheaper
- Asset-owner might not agree or take a better deal from a competing interest

Potential Ecological Benefits:

- In conjunction with a functional fishway could allow (increased) movement both ways
- In absence of a fishway, could improve downstream movement of early life history stages
- If exotic fish move more, operation could be used to differentially control exotics provided power generation is not compromised (which is the primary purpose of construction)
- Could improve current mortality rate that seen at existing weirs
- Could provide an opportunity for ‘green’ projects on a local scale that could be supported by the wider community thus growing regional industries that are sustainable

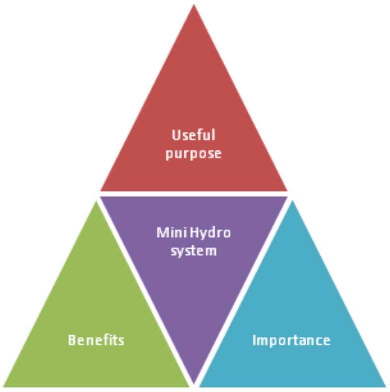
3. SUPPORTING MATERIAL PRODUCED IN THE WORKSHOP

3.1 The Value Factors

It is useful, in exercises such as this one, to establish a set of value factors, as defined in the Australian Standard for Value Management - AS 4183-2007. Whilst this workshop was not intended to be a Value Management study, the capture of value factors from multiple perspectives helps to give sharp focus to the exercise and gives everyone participating in the workshop the opportunity to put forward his or her view points, thus establishing shared knowledge and understanding.

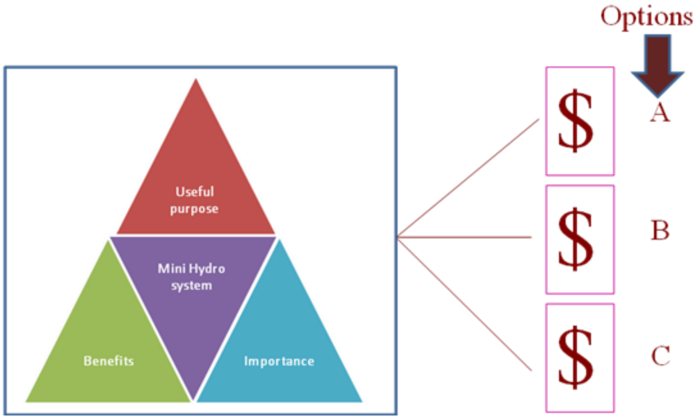
The ‘value factors’ of any entity (in this case, mini hydro systems) are defined as the combination of the useful purposes fulfilled by that entity, the beneficial outcomes from fulfilling those purposes and those other features/characteristics of the entity that are of particular importance or consequence. These three factors – useful purposes, benefits and important characteristics – in combination, determine the value placed on the entity from multiple perspectives.

It is important to recognise that the *perceptions* of purpose, benefits and importance differ from person to person and, from organisation to organisation and so one task of this workshop was to capture those perceptions, understand and record them in a structured format. This concept of value is illustrated in the following diagram.



Value

The value factors feed into the notion of *value for money* (as shown in the following diagram). In this workshop, we did not pursue the notion of value for money: that will be dealt with in due course. The diagram is shown here for the sake of completion in presenting the value factors.



Value for money

3.1.1 Primary purposes of mini hydro systems

The first value factor to be considered was the “primary purpose(s)” of mini hydro systems.

The primary purposes of mini hydro systems are to:

- Generate low-carbon electricity to regional areas
- Utilise existing infrastructure and resources
- Harness potential energy
- Make an economic return
- Contribute to the renewable energy mix

3.1.2 Beneficial outcomes

By fulfilling these primary purposes, “we” will be able to:

- Enhance the economy - local, state, and federal
- Provide regional benefits
- Enhance community acceptance
- Add value to existing assets
- Give potential for a safer passage for fish than existing passages
- In principle provide potential environmental offsets - e.g. fish passage, for larger infrastructure projects in the system
- Dispatch electricity
- Augment grid and improve reliability
- Drive down electricity bills
- Reduce green house gas emissions
- Demonstrate and meet renewable energy targets

3.1.3 Important characteristics or features of mini hydro systems

The third and final value factor to be dealt with was the set of important characteristics or features of mini hydro systems as perceived by the various representatives. The important characteristics/features were first captured at random and then structured into the following format.

FISH

- Fish survival
- May enhance future rehabilitation efforts, especially if downstream passage is improved
- Research can lead to better understanding of fish
- Net benefit to native fish population by improving downstream passage at some sites
- May draw fish away from fishway entrances, or may provide an opportunity to design fishways that use discharge from the hydro unit to attract fish to a specific area

ENVIRONMENT

- Whilst not required by legislation, construction of mini hydro systems may realistically result in a net environmental benefit
- Provide power with less changes to the river environment
- Replaces higher carbon energy sources
- Need to be evidence-based – environment/society/economy
- Potential to be a world leader in fish-friendly mini hydro
- Reduced environment and economic impact of power lines (closer to the source)
- Low footprints – what other infrastructure is required?
- Competitive renewable energy
- Alternative source of renewable energy

ELECTRICITY

- Need to generate usable electricity
- Reliable and on-going performance – longevity
- Power can be generated when it’s needed

ECONOMIC and FINANCIAL

- Long term economically sustainable
- Financial return
- Other water-users are not compromised by installation of mini hydro

REGIONS/COMMUNITY

- Potential for broad regional benefit
- Remote power generation for local community
- Community acceptance
- Meet development goals

Use of the value factors

The value factors were used as a basis for developing shared knowledge and understanding amongst the participants about mini hydro systems; to provide everyone participating in the workshop the opportunity to put forward their points of view; and, to provide a point of reference on ongoing discussion.

3.2 The "Ideal" Scenario

The first stage of the workshop – Building Shared Knowledge and Understanding – was brought to closure by spending a few moments reflecting upon what might be the "ideal scenario" from the perspectives of researchers, consent authorities and development companies. This session provided a reference for developing and assessing proposals later in the workshop.

RESEARCHERS

- Quantify the baseline mortality at existing structures
- Identify the mechanisms that kill and injure fish – thresholds
    - Lab trials
    - Field trials
- Improving the current situation
- Identifying the most susceptible species/life stages – narrow search
- Improving knowledge base of native fish

CONSENT AUTHORITIES

1. Need to define biological criteria against which a development application would be assessed. This should include definition of baseline conditions and biological requirements. These criteria are available to help guide development in other countries, but not yet in Australia.
2. Detailed information (fish ecology and physiology, on-ground proposals) to access impacts
    - No negative impacts
    - Improvement to ecological condition
    - Minimal uncertainty
    - Ongoing qualitative monitoring balancing risk and uncertainty
3. Would prefer a trial on low-risk habitat (e.g. irrigation channel)

DEVELOPMENT COMPANIES

- Need a clear understanding of data and research needs
- Understanding of how the research outputs feeds into policy and decision making
- State government funding of research due to wider benefits
- Research meets requirements of regulators/decision makers for both development and operation
- Have a clearly-defined set of acceptable biological criteria for mini hydro operation and construction. This could potentially be achieved through the provision of an acceptable guidelines document, or something similar.

3.2 Table of proposals and recommendations

The following table presents all proposals developed in the workshop, together with the recommendations against each proposal, including those that were discarded.

PROPOSALS	RECOMMENDATIONS (Requirements that must be met to enable the development and initiation of a research program)
1. Research requirements for mini Hydro	
PRE CONSTRUCTION ***Field-based investigations***	
* Sensor Fish trials – quantify baseline pressure / shear / velocity etc	YES - REQUIREMENT
Compare: Undershot / overshot / proposed hydro / natural river channel	YES - REQUIREMENT
* Investigate 'real world' actual mortality at undershot gates	*(Maybe – subject to further consideration)
* Perform combined Sensor Fish / live fish studies with different release depths to determine potential factors influencing welfare.	*(Maybe – subject to further consideration)
* What fish are located at the study site? Which of those may be impacted?	YES - REQUIREMENT
* Consider a well-designed before/after study to look into potential benefits/impacts post construction.	YES - REQUIREMENT
* Need to consider lethal and sub lethal effects	YES - REQUIREMENT
Lab-based investigations	
* Barotrauma work: What are the critical tolerances for fish? At what life history stage? – rate of change important	YES - REQUIREMENT
* Shear flume: What are critical values of shear? Does this differ among species and life stages?	YES - REQUIREMENT
* Develop fish-movement information to categorise/prioritise risk to species in the region. (Desktop study)	YES - REQUIREMENT
Additional knowledge needs:	
* What level of mortality is acceptable?	YES - REQUIREMENT
* What percentage of the population must be passed to sustain existing populations?	YES - REQUIREMENT
* Need to establish performance standards for operation.	YES – REQUIREMENT BUT MUST RECOGNISE THAT IS A LONG TERM GOAL AND SHOULD NOT HALT INITIAL PROGRESS.
* Can be achieved through large-scale tag-recapture studies. But how to do for larvae?	NO – BUT NEEDS TO BE PROVIDED BY CONSENT AUTHORITIES TO HELP GUIDE CONSTRUCTION
* Which fish are physoclists and which are physostomes?	NO

PROPOSALS	RECOMMENDATIONS (Requirements that must be met to enable the development and initiation of a research program)
Desktop investigations * What stages of development do physoclists develop gas regulating structures?	NO
POST CONSTRUCTION Field-based investigations * Is the hydro plant meeting biological performance standards? * Is the plant improving the situation / is it better than undershot weirs? Is the fish community recovering as expected? Is it better than a rehabilitated/removed structure? (i.e. Overshot weir) * Sensor Fish: Do actual hydraulic conditions meet expected conditions (first site only) * Blade strike: What are expected losses of fish through blade strike? What species are susceptible? * Continue before / after work.	Pursue these items to develop further knowledge and understanding – they are not essential requirements for initiating and developing the research program
2. Policy	
Need fundamental, independent, reductionist, research to inform general mechanisms injury, mortality, survival This will enable preliminary guidelines to be produced for developers/regulators	Supports research recommendations (above)
At a project proposal stage have some evidence of hydraulic performance of technology and how it compares to status quo at site. Site by site basis for consideration rather than technology by technology basis. Pilot trial evidence carries more weight than modelled data	Policy guideline Policy guideline Bridge between research and policy – first projects tested *in situ*
Focus on protect most vulnerable life stages	Policy guideline
What are reasonable offsets	Policy guideline to outline how fish-friendly mini hydro can form an acceptable offset for larger development projects.
3. CONSTRUCTION	
Creation of regulatory environmental management certainty (i.e. provision of benchmarks of acceptable impacts, sufficiency of experimental data/methods/processes, definition of 'significance').	Research/Pilot/Policy – Circular feedback loop to guide ongoing development but should not preclude an initial pilot project. We will only learn by doing. Expert panel approach with round table representation from research,

PROPOSALS	RECOMMENDATIONS (Requirements that must be met to enable the development and initiation of a research program)
	developers and consent authorities badly needed to clarify processes. Flow chart bridging science/policy This can proceed in parallel with the research and adaptively-managed as new information becomes available.
Less subjectivity in environmental assessment requirements. Engagement by researchers/regulators in environmental assessment proposals at an early stage in order to provide greater levels of guidance.	This comes after the research but the consent authorities must have an active role in informing the process by setting clear guidelines. This has been, and continues to, guide mini hydro development in other countries
PROPOSAL: Recognition of the reliable nature of supply with mini hydro technology in comparison of other renewable energy technologies (fair value of power incorporating reliability, close-to-region etc).	Note
PROPOSAL: Stability of price in regard to Renewable Energy Certificates (RECs) (e.g. $50 per MWh?).	Note
PROPOSAL: Greater available experimental (fish impact) data available to industry / required by regulators (i.e. lack of baseline data from impacts from existing weirs).	Research outcome which would be aided by formation of expert panel.
Ability to extrapolate data from other experimental impact research for use in mini hydro applications.	Research outcome
Greater facilitation/funding/in-kind research provided by regulators.	Research outcome
Potential Ecological Benefits: In conjunction with fishway could allow (increased) movement both ways If exotic fish move more, operation could be used to differentially mince exotics Could improve current mortality rate Potential for investing in local environmental projects	The 'benefits' need to be formally recognised along with potential 'negative' aspects. A tendency to focus too much on perceived negative attributes when, in actual fact, it may help improve existing situations at some sites.

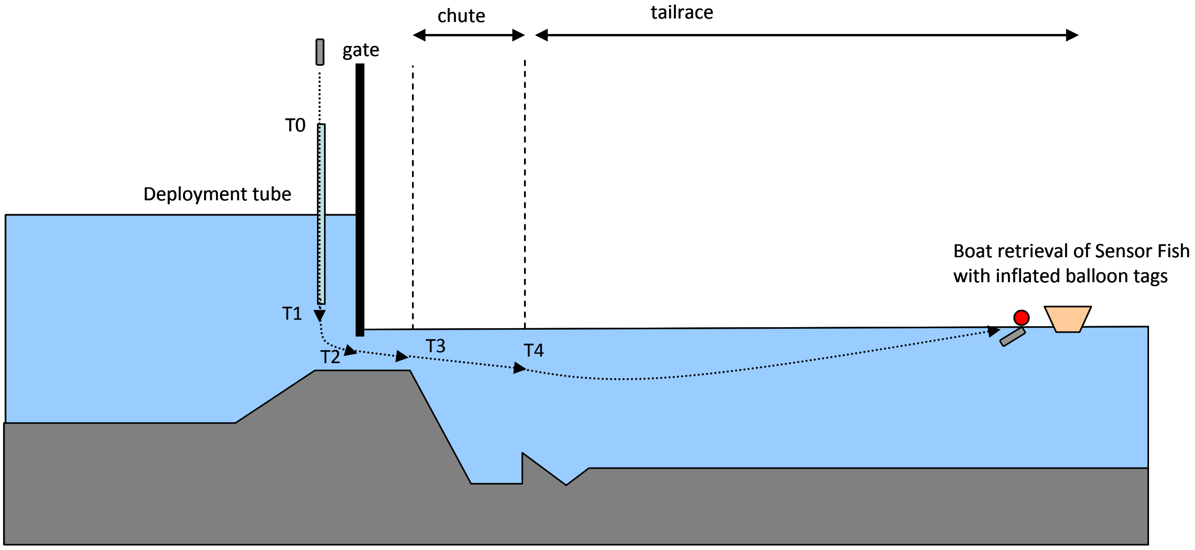
APPENDIX A – WORKSHOP PARICIPANTS

First name	Surname	Position/ Title	Organisation or Division
Robert	Stokes	Parliamentary Secretary for Renewable Energy	Liberal MP for Pittwater NSW Legislative Assembly
Lee	Baumgartner	Senior Research Scientist	NSW Fisheries (Department of Primary Industries)
Craig	Boys	Research Scientist	NSW Fisheries (Department of Primary Industries)
Matthew	Gordos	Senior Conservation Manager	NSW Fisheries (Department of Primary Industries)
Andrew	Jones	Executive Director	Waratah Power
Martin	Mallen-Cooper	Consultant	Fishway Consulting Services
Sarah	Fairful	Manager - Aquatic Ecosystems Unit	NSW Fisheries (Department of Primary Industries)
Paul	Butler	Principal Energy Advisor	Trade and Investment NSW
Daniel	Deng	Senior Researcher	Pacific Northwest National Lab
Rich	Brown	Senior Researcher	Pacific Northwest National Lab
Soulivanthong	Kingkeo	Deputy Director General	National Agriculture and Forestry Research Institute
Oudom	Phonekhampeng	Dean of Science (Agriculture)	National University of Lao
Garry	Thorncraft	Research Associate	National University of Lao
Will	Glamour	Hydraulic Engineer	Water Resources Laboratory
Brett	Miller	Hydraulic Engineer	Water Resources Laboratory
Adam	Vey	Development manager	State and Regional Development
Wayne	Robinsonon	Biometrician	NSW Fisheries (Department of Primary Industries)
Angus	Northey	Environmental Consultant	Consultant
Arthur	Watts	Director	Waratah Power
Michelle	Chung	Senior Policy Advisor	Office of Environment and Heritage
Bob	Creese	Research Leader	Trade and Investment NSW
Lisa	Peterson	State Manager	Ausindustry
Roy	Barton	Facilitator	Australian Centre for Value Management

APPENDIX B – WORKSHOP AGENDA

Time	Item	Officer
9.30	Welcome – Parliamentary Secretary for Renewable Energy	Rob Stokes
	Workshop preliminaries	Roy Barton
	1. BUILD SHARED KNOWLEDGE and UNDERSTANDING	
	Briefly describe the context in which the workshop is being held	L. Baumgartner
	Establish the *value factors* of mini hydro systems: • The *primary purposes* of mini hydro systems • The *benefits* that flow from using mini hydro systems • *Characteristics* of mini hydro systems that are seen to be of *particular importance or significance*	Whole group
	Morning Tea	
	Present information about: • Proposed mini hydro development in Australia + *Q&A* • Welfare of fish during downstream passage + *Q&A* • Development applications and consent process in NSW + *Q&A*	A. Jones L. Baumgartner A. Northey and Sarah Fairfull
	Capture the "ideal scenario" from the perspectives of the consent authorities, researchers and development-companies	Whole group
	Summarise the key issues	Whole group
12.30	Lunch	
1.00	**2. MAKE PROPOSALS FOR REQUIREMENTS** *Work in focus groups to make proposals for:* ○ Research: data requirements and implications for assessing species survivability, including factor combinations. *(e.g. what do we need to know? How do we do it?)* ○ Policy: requirements for biological data that will form the basis for application consent. *(e.g. what are knowledge-gaps? What is precluding endorsement of concepts?)* ○ Construction: *e.g. what are the needs of renewable energy industry, what is the supply potential in NSW, what are the barriers to implementation, can we improve the baseline?* ○ Other issues that arise during the workshop	Focus groups
	3. CONSIDER THE PROPOSALS Re-convene as a whole group to consider/modify the recommendations of the focus groups	Whole group
	Afternoon tea	
	4. SEEK AGREEMENT TO THE WAY AHEAD Seek agreement to the requirements that that must be met to enable the development and initiation of a research program into the use of fish-friendly, mini-hydro facilities in NSW. In the event of agreement not being reached, seek agreement to further actions that need to be pursued to reach agreement later.	Whole group
	5. SET UP AN ACTION PLAN	
	Set up a plan (actions/dates/nominees) to implement the workshop's recommendations and to deal with any issues that arise during the day.	Whole group
16.45	Close the workshop and delegates depart	

APPENDIX 2 – SENSOR FISH DATA SHOWING PRESSURE, ACCELERATION, MAGNITUDE, AND ANGULAR VELOCITY MAGNITUDE TIME HISTORIES FOR EACH RELEASE



The time (seconds) that each Sensor Fish transitioned between zones. In the plots that follow, the time axis was adjusted so that T2 equals zero.

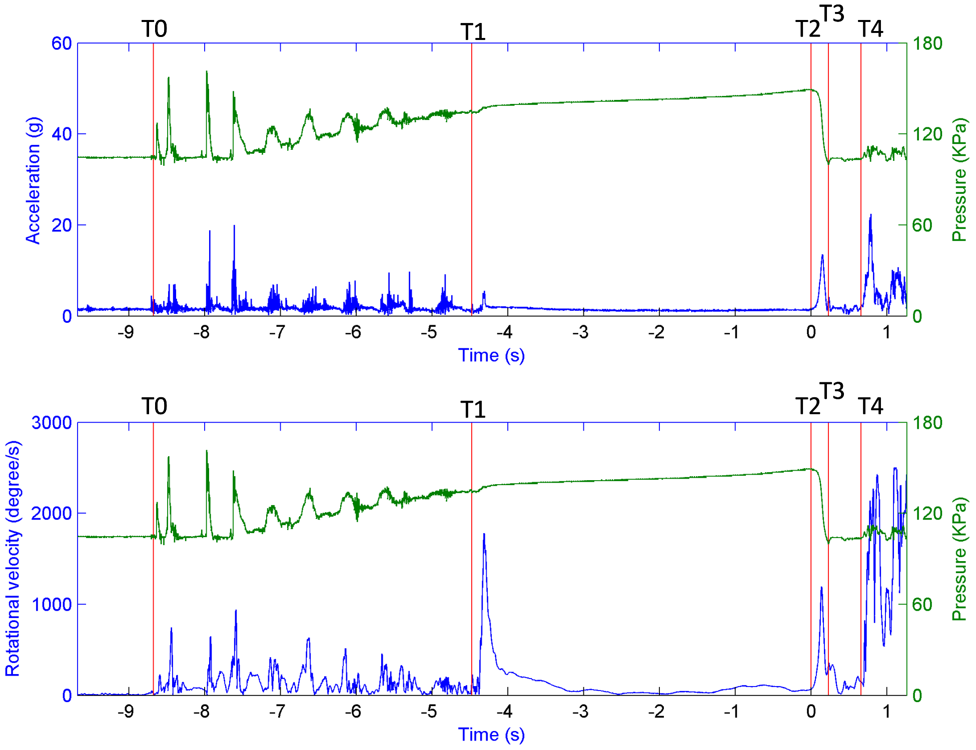
Zone		**Enter pipe**	**Exit pipe**	**Enter gate**	**Enter chute**	**Enter tailrace**
Transition marker		T0	T1	T2	T3	T4
Run	Release no.	sec	sec	sec	sec	sec
1	1	12.64	16.84	21.32	21.55	21.98
2	2	17.2	20.36	24.22	24.42	24.8
3	4	8.201	11.47	15.05	15.29	15.66
4	5	8.252	12.26	15.58	15.84	16.31
5	7	9.59	12.04	16.18	16.37	16.84
6	8	8.407	12.56	15.08	15.26	15.74
7	9	7.474	13.32	17.7	17.95	18.38
8	10	6.265	11.06	14.27	14.51	14.99
9	12	6.229	10.1	12.26	12.49	13.01
10	13	5.2	11.32	13.37	13.58	14.06
11	14	4.912	9.409	11.22	11.44	11.9
12	15	6.987	12.16	14.05	14.26	14.65

Sensor Fish data summary upstream of gate

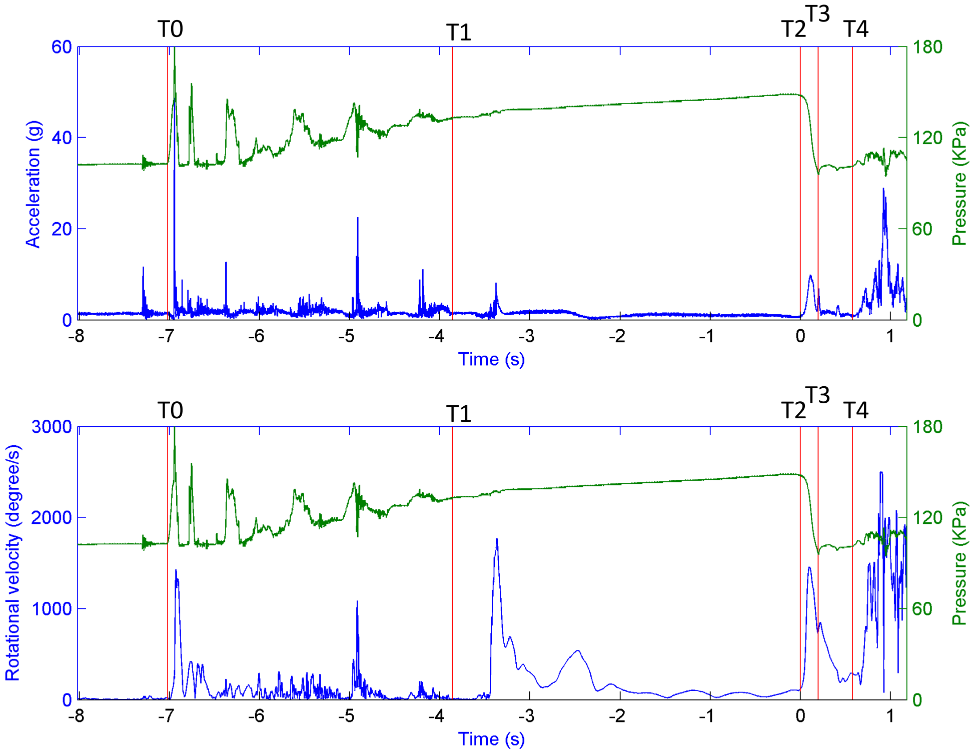
		In the pipe (T0-T1)						**From pipe to gate (T1-T2)**							
		Max Pressure	Max Pressure	Min Pressure	Min Pressure	Max Accel.	Max Rotational	Max Pressure	Max Pressure	Min Pressure	Min Pressure	Pressure change	Pressure change speed	Max Accel.	Max Rotational
Run	Op. no.	psia	KPa	psia	KPa	g	degree/s	psia	KPa	psia	KPa	KPa	KPa/sec	G	degree/s
1	1	23.46	161.78016	14.37	99.09552	20	940.4	21.70	149.6432	19.35	133.4376	16.2056	3.617321429	5.5	1779.6
2	2	27.17	187.36432	14.37	99.09552	48.7	1428.1	21.60	148.9536	19.26	132.817	16.13664	4.180476684	8.2	1771.4
3	4	24.73	170.53808	14.08	97.09568	19.1	1169.9	21.02	144.9539	19.16	132.1274	12.82656	3.582837989	6.6	1172
4	5	25.61	176.60656	13.88	95.71648	49.5	972.6	21.51	148.333	19.26	132.817	15.516	4.673493976	3.6	1615.6
5	7	20.04	138.19584	12.90	88.9584	123.2	1420.4	21.60	148.9536	19.55	134.8168	14.1368	3.41468599	7.7	1567.1
6	8	21.51	148.33296	13.29	91.64784	55.9	1162.0	21.11	145.5746	18.38	126.7485	18.82608	7.470666667	3.4	648.9
7	9	19.45	134.1272	12.41	85.57936	63.1	1114.8	21.41	147.6434	18.87	130.1275	17.51584	3.999050228	3.5	239.5
8	10	18.77	129.43792	14.47	99.78512	48.4	617.5	21.02	144.9539	18.67	128.7483	16.2056	5.04847352	3.3	812.8
9	12	18.96	130.74816	13.00	89.648	97.4	1325.1	21.02	144.9539	18.87	130.1275	14.8264	6.864074074	2.3	1303.1
10	13	19.16	132.12736	14.27	98.40592	18.3	1258.1	21.02	144.9539	18.96	130.7482	14.20576	6.929639024	3.4	228.8
11	14	18.96	130.74816	14.47	99.78512	20.2	762.4	20.92	144.2643	18.77	129.4379	14.8264	8.186858089	2.0	302.1
12	15	19.26	132.81696	14.08	97.09568	11.2	777.1	20.92	144.2643	18.57	128.0587	16.2056	8.574391534	4.3	680.8

Sensor Fish data summary downstream of gate

		From gate to chute (T2-T3)									**From chute to tailrace (T3-T4)**					
		Max Pressure	Max Pressure	Depth	Min Pressure	Min Pressure	Pressure change	Pressure change speed	Max Accel.	Max Rotational	Max Pressure	Max Pressure	Min Pressure	Min Pressure	Max Accel.	Max Rotational
Run	Op. no.	psia	KPa	meter	psia	KPa	KPa	KPa/sec	g	degree/s	psia	KPa	psia	KPa	g	degree/s
1	1	21.60	148.9536	4.86	14.47	99.78512	49.16848	213.776	13.5	1194	15.15	104.474	14.47	99.78512	4.2	356.3
2	2	21.51	148.33296	4.80	13.88	95.71648	52.61648	263.0824	9.9	1459.1	14.86	102.475	13.88	95.71648	6.9	850.5
3	4	21.02	144.95392	4.45	13.88	95.71648	49.23744	205.156	14.3	851.1	14.27	98.4059	13.88	95.71648	5.4	520.7
4	5	21.51	148.33296	4.80	13.88	95.71648	52.61648	202.3710769	11.2	664.2	14.86	102.475	13.88	95.71648	6.5	781.2
5	7	21.60	148.9536	4.86	14.37	99.09552	49.85808	262.4109474	12.4	804.3	15.25	105.164	14.37	99.09552	4.9	510.4
6	8	20.92	144.26432	4.38	13.69	94.40624	49.85808	276.9893333	12.5	1351.9	14.37	99.0955	13.69	94.40624	4.5	689.0
7	9	21.31	146.95376	4.66	13.69	94.40624	52.54752	210.19008	11.3	442.7	14.66	101.095	13.78	95.02688	4.3	394.1
8	10	21.02	144.95392	4.45	14.17	97.71632	47.2376	196.8233333	13.0	812.2	14.57	100.475	14.17	97.71632	4.2	570.2
9	12	20.92	144.26432	4.38	13.88	95.71648	48.54784	211.0775652	16.1	1078.9	14.86	102.475	13.98	96.40608	2.7	894.5
10	13	21.02	144.95392	4.45	14.17	97.71632	47.2376	224.9409524	18.9	1293.9	14.57	100.475	14.17	97.71632	3.8	239.8
11	14	20.92	144.26432	4.38	14.08	97.09568	47.16864	214.4029091	12.3	793.6	14.66	101.095	13.98	96.40608	5.8	1308.9
12	15	20.92	144.26432	4.38	14.27	98.40592	45.8584	218.3733333	15.8	1321.8	14.47	99.7851	14.17	97.71632	3.5	1095.6



Run 1 –Sensor Fish trace 3 m release depth Hay Weir



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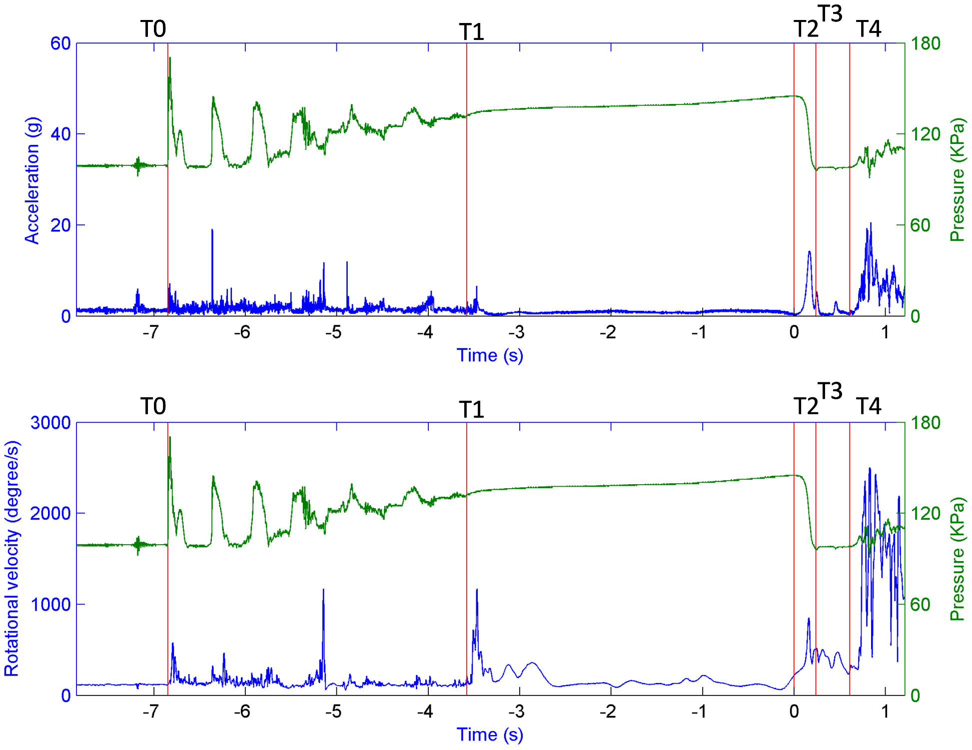

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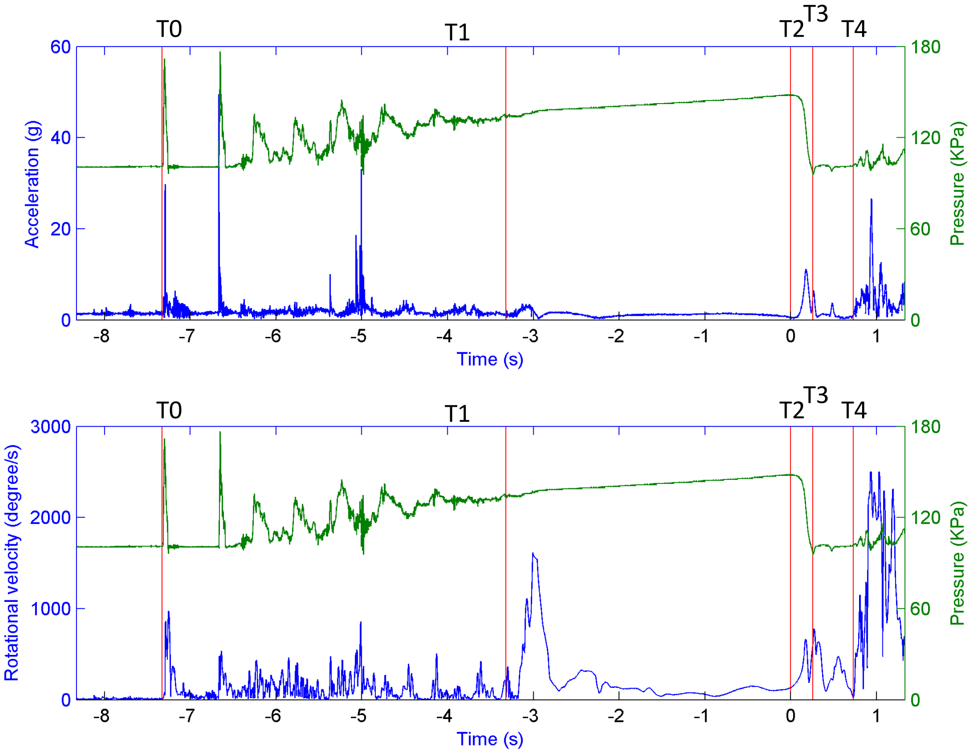

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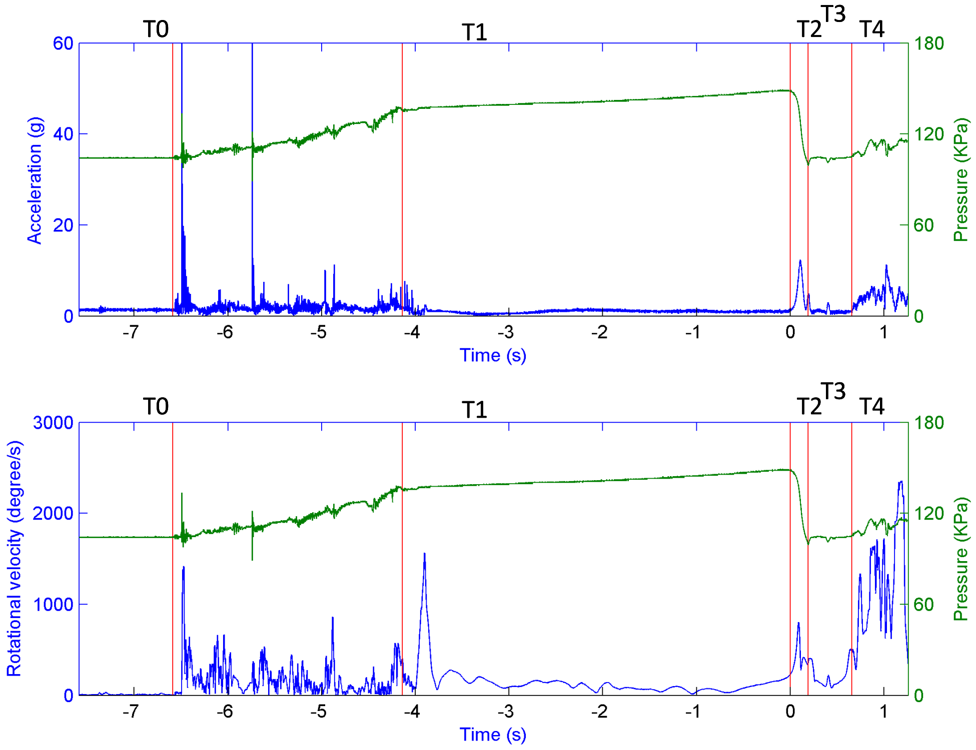

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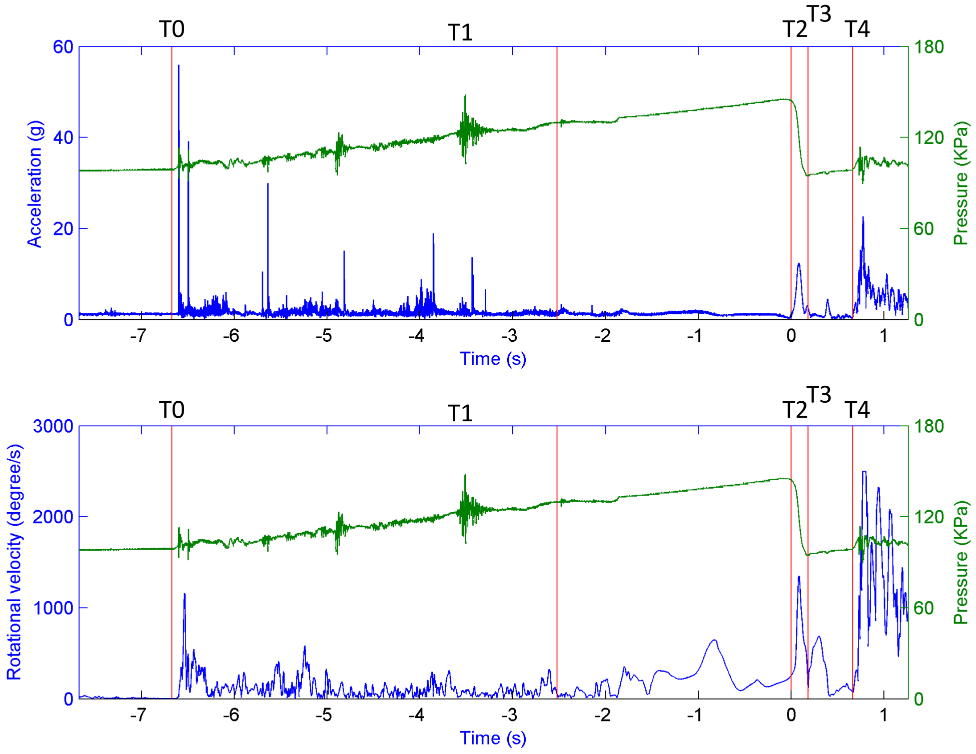

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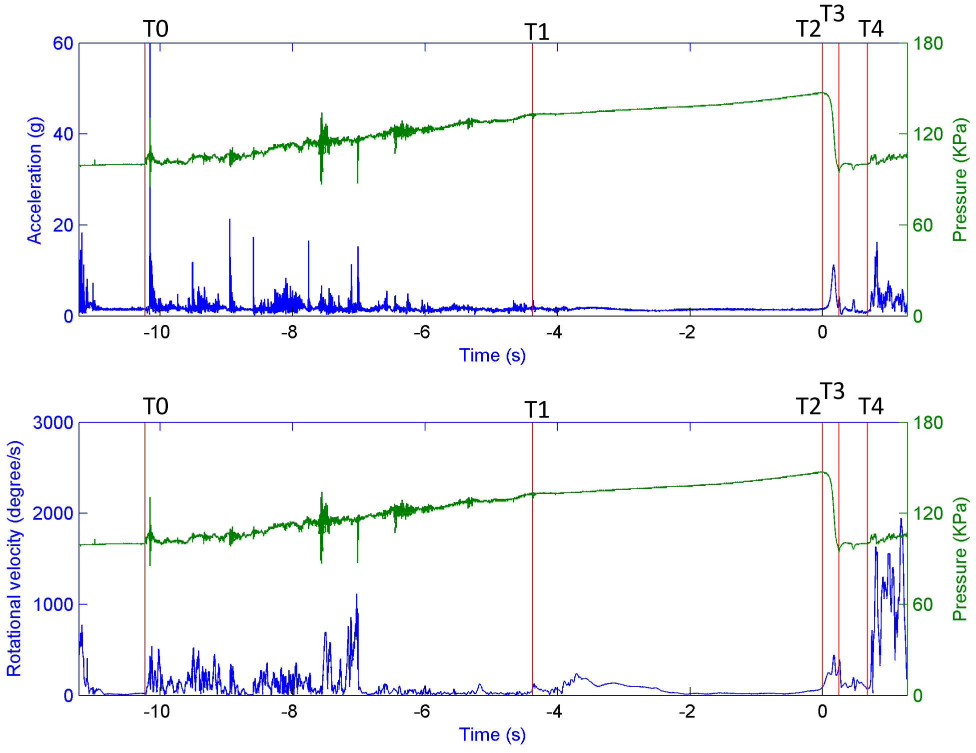
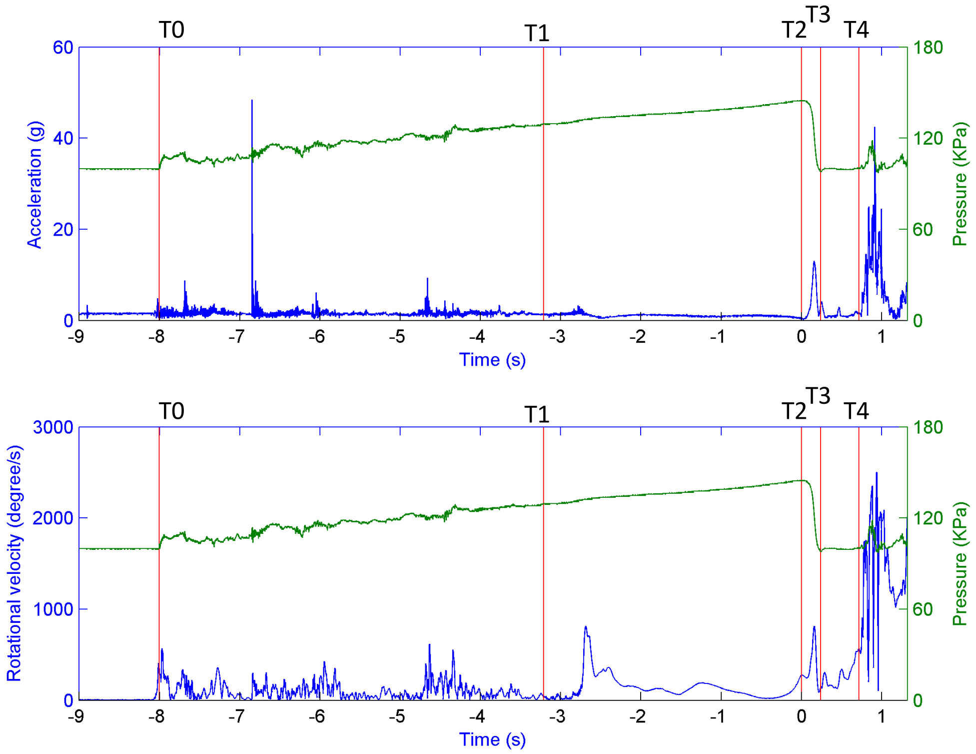
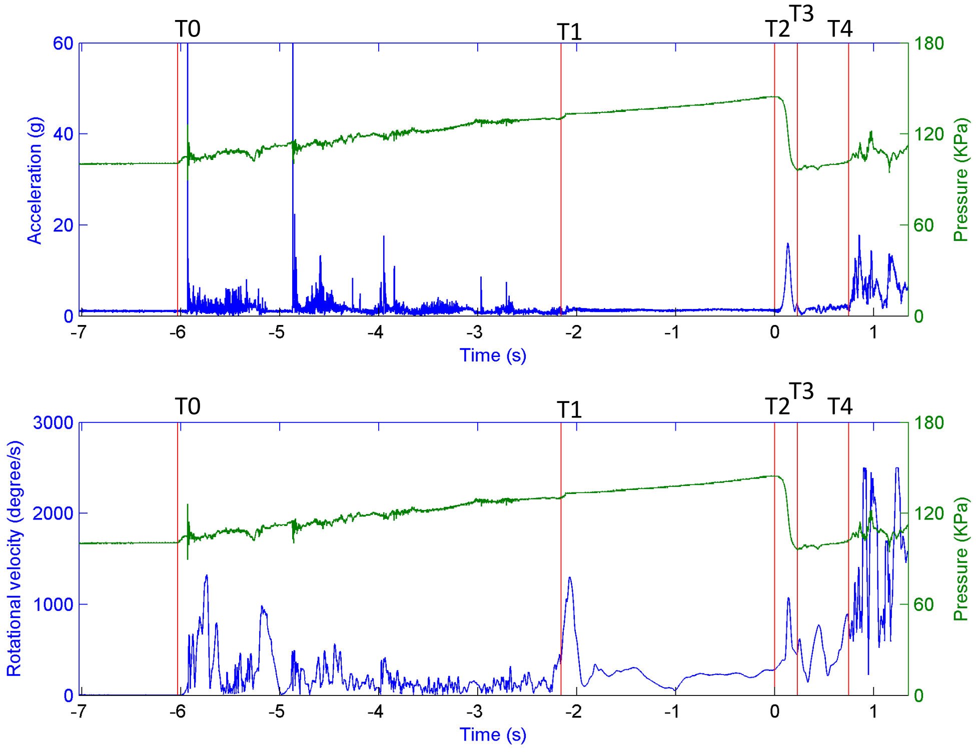


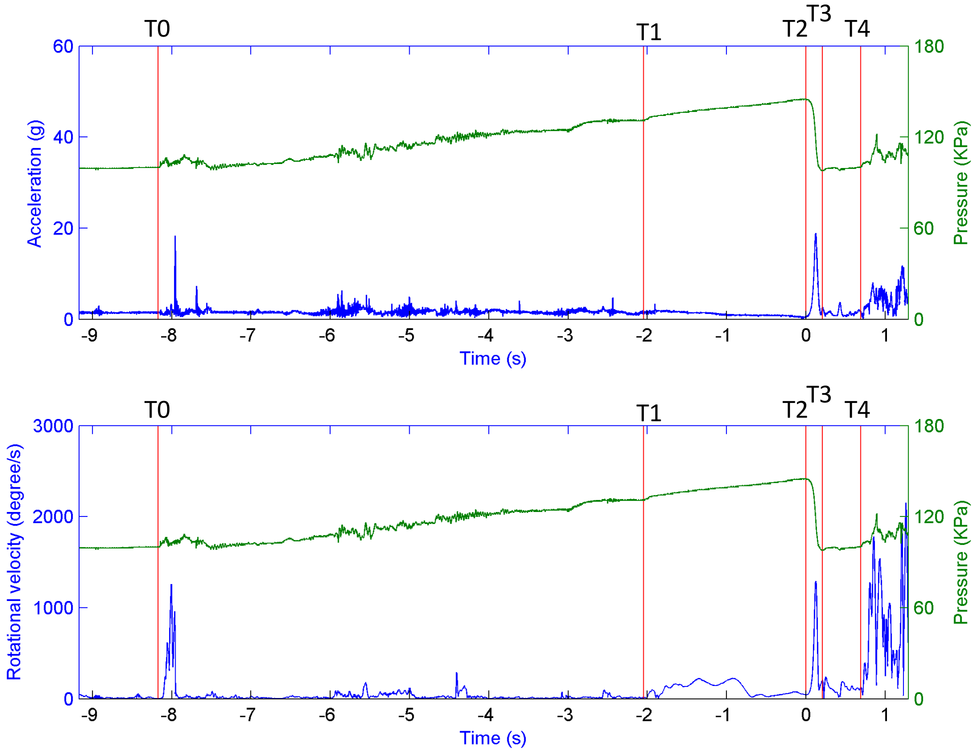
Run 7–Sensor Fish trace 3 m release depth Hay Weir



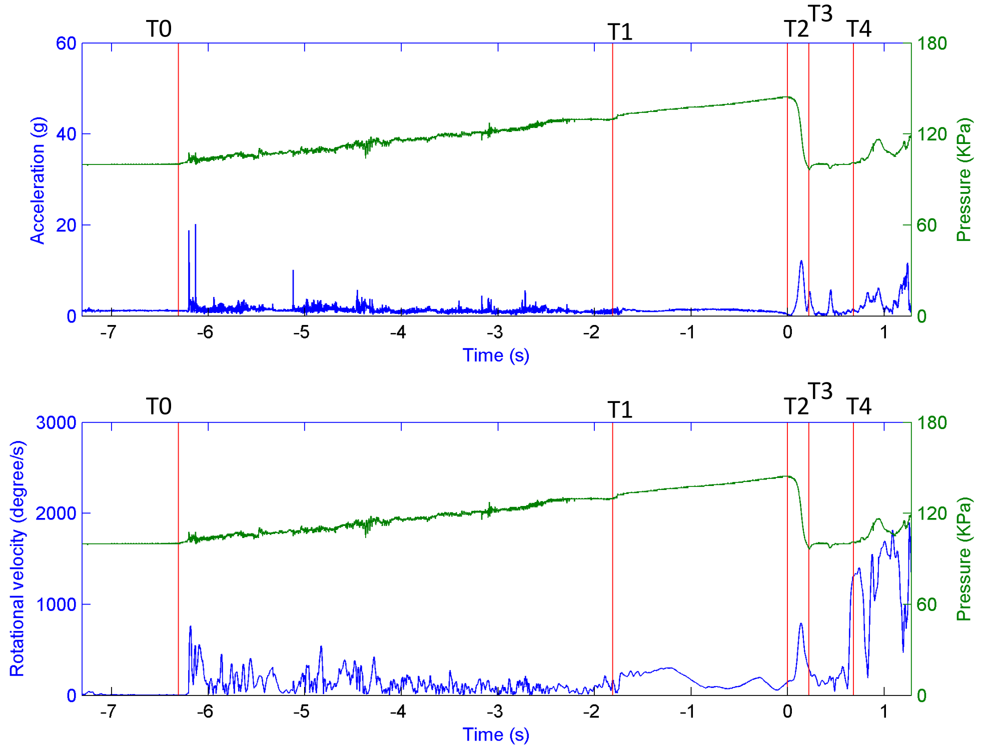
Run 8 –Sensor Fish trace 3 m release depth Hay Weir



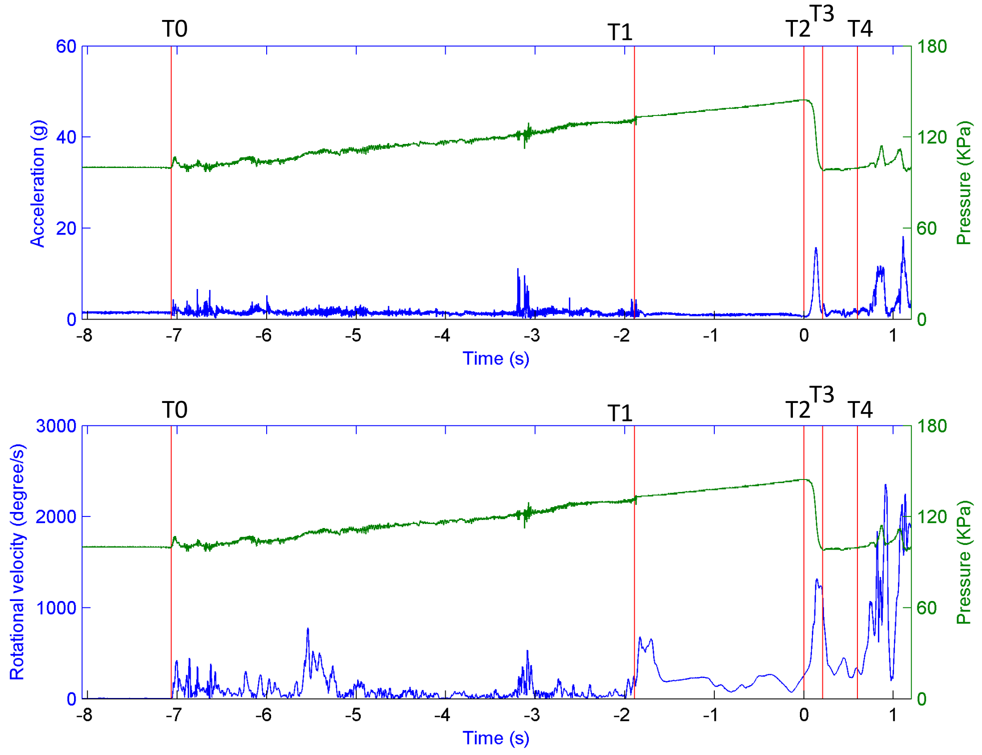
Run 9–Sensor Fish trace 3 m release depth Hay Weir



Run 10 –Sensor Fish trace 3 m release depth Hay Weir



Run 11–Sensor Fish trace 3 m release depth Hay Weir



Run 12 –Sensor Fish trace 3 m release depth Hay Weir

APPENDIX 3 – SUMMARY OF PRESSURE CHANGE MODELLED USING CFD FOR A VARIETY OF FLOW SCENARIOS AND GATE CONFIGURATIONS AT HAY WEIR

Summary of pressure change (Kpa) modelled using CFD for a variety of flow scenarios and gate configurations (see Table 2) at Hay Weir.

Scenario	Pressure	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Median	Min	Max
S01	Max	145.17	144.41	144.01	143.83	143.63	143.42	143.24	143.05	143.73	143.05	145.17
	Min	100.68	100.58	100.48	100.39	100.29	100.19	100.09	97.97	100.34	97.97	100.68
	Diff	-44.49	-43.83	-43.53	-43.44	-43.34	-43.23	-43.15	-45.08	-43.49	-45.08	-43.15
	% Diff	-30.65	-30.35	-30.23	-30.20	-30.17	-30.14	-30.12	-31.51	-30.21	-31.51	-30.12
S02	Max	140.10	138.55	137.26	136.13	135.57	135.35	135.04	134.59	135.85	134.59	140.10
	Min	100.00	101.71	101.44	101.16	100.89	100.62	98.97	97.24	100.76	97.24	101.71
	Diff	-40.10	-36.84	-35.82	-34.97	-34.68	-34.73	-36.07	-37.35	-35.95	-40.10	-34.68
	% Diff	-28.62	-26.59	-26.10	-25.69	-25.58	-25.66	-26.71	-27.75	-26.34	-28.62	-25.58
S03	Max	143.15	140.68	139.02	137.60	136.22	135.92	135.56	135.28	136.91	135.28	143.15
	Min	100.00	101.92	101.54	101.18	100.82	100.45	99.79	93.35	100.64	93.35	101.92
	Diff	-43.15	-38.76	-37.48	-36.42	-35.40	-35.47	-35.77	-41.93	-36.95	-43.15	-35.40
	% Diff	-30.14	-27.55	-26.96	-26.47	-25.99	-26.10	-26.39	-30.99	-26.71	-30.99	-25.99
S04	Max	110.00	151.60	144.18	141.70	140.14	138.48	137.98	137.56	139.31	110.00	151.60
	Min	100.00	100.00	101.71	101.32	100.97	100.60	100.20	98.58	100.40	98.58	101.71
	Diff	-10.00	-51.60	-42.47	-40.38	-39.17	-37.88	-37.78	-38.98	-39.08	-51.60	-10.00
	% Diff	-9.09	-34.04	-29.46	-28.50	-27.95	-27.35	-27.38	-28.34	-28.14	-34.04	-9.09
S05	Max	110.00	157.60	147.29	144.30	142.28	140.38	139.75	139.26	141.33	110.00	157.60
	Min	100.00	100.00	101.28	100.97	100.72	100.46	100.19	96.54	100.33	96.54	101.28
	Diff	-10.00	-57.60	-46.01	-43.33	-41.56	-39.92	-39.56	-42.72	-42.14	-57.60	-10.00
	% Diff	-9.09	-36.55	-31.24	-30.03	-29.21	-28.44	-28.31	-30.68	-29.62	-36.55	-9.09
S06	Max	117.76	115.27	114.35	113.72	113.38	113.03	112.77	112.62	113.55	112.62	117.76
	Min	100.00	100.00	100.00	100.00	100.00	100.00	98.96	97.20	100.00	97.20	100.00
	Diff	-17.76	-15.27	-14.35	-13.72	-13.38	-13.03	-13.81	-15.42	-14.08	-17.76	-13.03
	% Diff	-15.08	-13.25	-12.55	-12.06	-11.80	-11.53	-12.25	-13.69	-12.40	-15.08	-11.53
S07	Max	121.92	118.37	116.82	115.64	114.48	114.14	113.88	113.83	115.06	113.83	121.92
	Min	100.00	102.23	101.78	101.33	100.89	100.55	100.06	97.79	100.72	97.79	102.23
	Diff	-21.92	-16.14	-15.04	-14.31	-13.59	-13.59	-13.82	-16.04	-14.68	-21.92	-13.59
	% Diff	-17.98	-13.64	-12.87	-12.37	-11.87	-11.91	-12.14	-14.09	-12.62	-17.98	-11.87
S08	Max	110.00	125.54	120.20	118.01	116.65	115.20	114.69	114.48	115.93	110.00	125.54
	Min	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.68	100.00	99.68	100.00
	Diff	-10.00	-25.54	-20.20	-18.01	-16.65	-15.20	-14.69	-14.80	-15.93	-25.54	-10.00
	% Diff	-9.09	-20.34	-16.81	-15.26	-14.27	-13.19	-12.81	-12.93	-13.73	-20.34	-9.09
S09	Max	130.99	123.26	120.89	118.91	117.82				120.89	117.82	130.99
	Min	100.00	101.94	101.36	100.80	100.28				100.80	100.00	101.94
	Diff	-30.99	-21.32	-19.53	-18.11	-17.54				-19.53	-30.99	-17.54
	% Diff	-23.66	-17.30	-16.16	-15.23	-14.89				-16.16	-23.66	-14.89
S10	Max	124.04	123.55	122.82	122.63	122.48	122.34	122.22	122.07	122.56	122.07	124.04
	Min	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.88	100.00	99.88	100.00
	Diff	-24.04	-23.55	-22.82	-22.63	-22.48	-22.34	-22.22	-22.19	-22.56	-24.04	-22.19
	% Diff	-19.38	-19.06	-18.58	-18.45	-18.35	-18.26	-18.18	-18.18	-18.40	-19.38	-18.18

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