Improving Fishway Design Through the Use of Detailed 2D and 3D Hydrodynamic Modelling

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Detailed 2D and 3D hydraulic modelling has been undertaken to inform and improve the design of several fishways in North-East Victoria. The hydraulic modelling has allowed hydraulic conditions within and around the new structures to be accurately understood. The modelling and design criteria aim to facilitate fish passage over and through the fishway structures. The modelling ensures a more robust design in that the required hydraulic conditions can be assessed across a range of flow conditions.

The paper presents two case studies of fishway design projects in North-East Victoria undertaken in partnership with the North East Catchment Authority and Arthur Rylah Institute, with funding provided by the Victorian State Government's Environmental Water: Works, Measures and Technical Investigations Program. Each location posed specific design challenges which were overcome through the use of innovative fishway design and detailed modelling. Detailed hydraulic modelling is a valuable tool used to support the design of new fishways to ensure the constructed fishway provides acceptable hydraulic conditions to facilitate fish passage.

1. INTRODUCTION

Fishways (also referred to as fish ladders) are structures typically constructed to facilitate the movement of fish past in-stream barriers such as weirs, vehicle crossings and dams. The fishway allows desirable hydraulic conditions to be achieved that enable the movement of fish which would otherwise be limited by physical barriers, high velocities or excessive changes in water level (Kapitzke 2010).

Hydrodynamic modelling can be a highly useful tool to inform and optimise the design of fishways to ensure the required hydraulic conditions have been satisfied whilst minimising construction costs. 2D or 3D modelling can be used for this purpose and each have advantages and disadvantages (Arrowsmith and Zhu 2014). 2D modelling is typically quicker to establish and produce results, whilst 3D modelling can be much more complex and time-consuming to set up but offers advantages in terms of considering the vertical distribution of velocities which can be an important advantage, particularly in vertical slot fishways where individual slot widths often vary in width. (Arrowsmith and Zhu 2014).

Over the past 18 months, 2D and 3D hydraulic modelling has been undertaken to inform and improve the design of several fishways in North-East Victoria in partnership with North East Catchment Authority, with funding provided by the Victorian State Government's Environmental Water: Works, Measures and Technical Investigations Program. This paper presents two case studies where 2D or 3D hydrodynamic modelling has been utilised to optimise fishway design and ensured key hydraulic criteria have been met, which facilitates the movement and mitigation of native fish. One of the examples below is an upgrade of a weir on the Ovens River whilst another is a weir upgrade on Snowy Creek, an alpine stream and tributary of the Mitta Mitta River. Hydraulic modelling of these sites has allowed hydraulic conditions within and around the new structures to be accurately understood under both current and design conditions. The modelling has ensured that the required hydraulic conditions have been achieved across a range of flow conditions.

2. CASE STUDY 1 - SNOWY CREEK FISHWAY

2.1. Overview

Snowy Creek is a non-regulated upper catchment tributary of the Mitta Mitta River, which joins the river at the Mitta Mitta township, approximately 400m downstream of the Snowy Creek Weir. The Snowy Creek has a contributing catchment area of approximately 436km^2 and is a relatively high energy stream, predominantly surrounded by densely vegetated hill slopes and occasional floodplain pockets utilised for agriculture.

The Snowy Creek Weir was constructed across Snowy Creek in the 1970's to provide a swimming hole for the local community. The weir is recognised as an important asset to the local community, drawing tourists who make use of the swimming area and complementary facilities and services. However, the Snowy Creek Weir is also known to impact on the movements of fish within Snowy Creek. Provision of fish passage through the Snowy Creek weir structure would allow fish passage through the entire Snowy Creek system as there are no other man-made barriers present.

The existing weir (Figure 1) is comprised of sheet pile with a concrete capped surface and is approximately 1.9m high, 18m long (perpendicular to the direction of flow) and approximately 4m wide. The weir incorporates two gates (or slots that allow water to pass through the structure) which are approximately 1.5m wide. Hardwood sleepers are placed into the gates to form a backwater (or pool) upstream of the weir, which is utilised for swimming during the warmer months (approximately November to March).

The structural integrity of the weir has been impacted by high flow events within Snowy Creek. Most notably, flooding in September 1998. In response to the damage sustained in the floods, the North East Catchment Management Authority received funding to prepare a detailed design for a replacement weir and fishway structure. The preferred arrangement, developed in close consultation with the relevant stakeholders and community was determined to be a new concrete weir incorporating a vertical slot fishway.

Figure 1 – Snow Creek Weir – existing structure

2.2. Hydrodynamic Modelling

2.2.1. Model Set Up

Two hydraulic models were set up to inform design of a new weir and fishway arrangement. A 2D model was developed to determine the broader flow and velocity distribution under existing conditions in Snowy Creek over the full range of likely flows. Important information included the flow conditions upstream and downstream of the existing weir and the flow velocities in and around the weir. This model was then modified to simulate the effect of the new weir arrangement and associated topography modifications on water levels and velocities in the creek.

A more detailed 3D local model of the proposed fishway itself was then developed to model the hydraulic conditions within the vertical slot fishway, to ensure conditions were suitable for fish passage. It should be noted that the 3D local model was not a CFD model and therefore is not able to fully replicate the vertical accelerations within the fishway structure. However overall it does provide a good representation of hydraulic conditions for the purposes of the fishway design.

2.2.2. 2D Snowy Creek Hydraulic Model

Detailed site survey was captured and converted into a digital elevation model (DEM) for use in the hydraulic model to represent existing conditions. This DEM was interpolated to a mesh, which is shown in Figure 2 below.

This DEM was then updated to represent design conditions after installation of the fishway structure. This updated DEM includes a series of baffles downstream of the weir and fishway and localised topographic smoothing, as shown in Figure 2. This baffle and topographic smoothing was included to ensure optimal conditions for fish entry to the fishway on the downstream side of the weir.

Figure 2 – Design Model Bathymetry

The weir has three gates in which drop boards can be inserted and removed to vary flow through the weir. The existing model was run for two expected weir scenarios – fully open dropboards (winter scenario) and closed dropboards (summer scenario - swimming season). To represent the open dropboard the topography was modified to allow flow through the openings where the gates are located.

2.2.3. 3D Fishway Hydraulic Model

The vertical slot fishway model was set up based on a conceptual design, then lengthened until the hydraulic requirements were met for fish passage.

The final configuration has an upstream invert of 264.0m AHD and a downstream invert of 263.7m AHD. The fishway is a total of 63m long, with 2 lanes as shown in Figure 3. These lanes are 27.5m and 35.5m long respectively, made up of 1.5 x 3.2m boxes, with two larger boxes on each end.

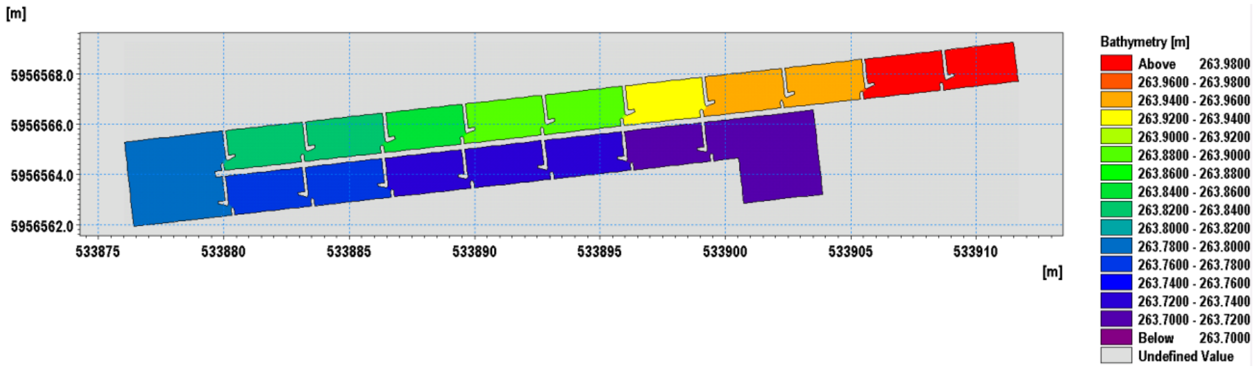

Figure 3 – Fishway 3D Model Bathymetry

2.2.4. Vertical Slot Fishway Results

Fishway design conditions, as specified by the fish ecologist on the project, required velocities less than 1.2m/s, depths greater than 0.5m, a minimum fishway slot gap of 0.25m and fishway turbulence to be less than 25W/m^3. The Snowy Creek structure was also complicated by the fact that the design and hydraulic conditions need to accommodate both native fish and Salmonids, which have quite different tolerances. A large number of fishway iterations were tested to ensure these hydraulic conditions were met, with results presented below.

Maximum fishway velocities for the full range of flows are presented below in Figure 4, with velocities never exceeding the critical 1.2m/s. Critical fishway depths are also presented in Figure 4, with fishway depths greater than 0.5m for all tested flow scenarios. The water surface levels through the fishway for the full range of scenarios is also visualised in Figure 4, showing the head drop through the fishway.

Turbulence was calculated in the fishway for the full range of flows using the formula below:

$$P = \rho g Q \Delta h V^{-1}$$

Where turbulence (energy dissipation, P) is proportional to water weight (ρg – **water density and gravity**), flow rate (Q), change in head over the structure (Δh) and inversely proportional to the water volume in the fishway. The fishway was consistently found to have turbulence in the 23-24W/m^3 range which is less than that specified by the project ecologist as required for native fish passage.

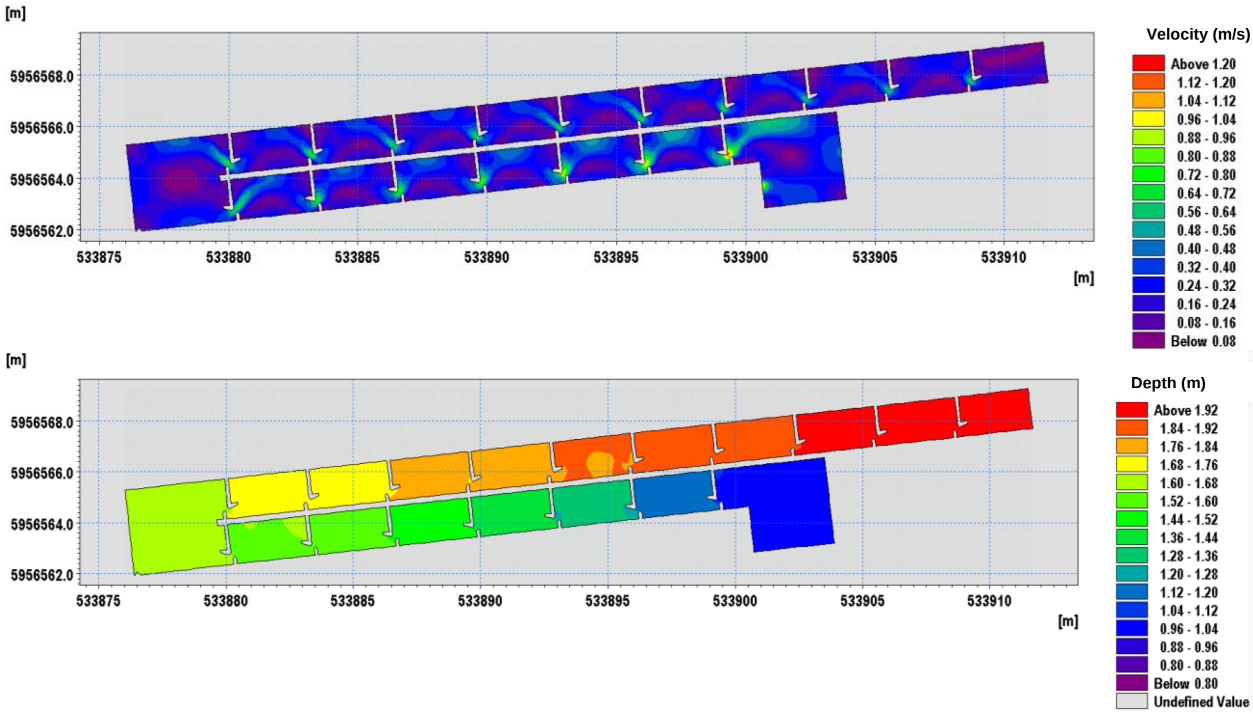

Figure 4 - Fishway peak velocity and critical depth

3. CASE STUDY 2 - TEAGARDEN WEIR, OVENS RIVER

3.1. Overview

The Ovens River is a largely non-regulated tributary of the Murray River, contributing 14% of the total flow in the Murray-Darling Basin. The North East Waterway Strategy (North East CMA, 2014) states that the Ovens River is one of two rivers listed in the Victorian River Health Strategy (2002), that requires special management because of its environmental values. The conservation value, natural water regime, and the relative intactness of the majority of the Ovens River system make it unique in the Murray-Darling Basin.

The high priority threatened migratory fish species, Golden Perch and Murray Cod, are found in the Ovens River up to Porepunkah, with Macquarie Perch in the Buffalo River catchment. Flat Headed Galaxias, a medium priority threatened migratory fish can be found between Porepunkah and Bright in the Ovens River. Trout Cod, a high priority endangered non-migratory fish are found in the Ovens River up to Porepunkah and in the Buffalo River (North East CMA, 2014).

The Tea Garden Weir is positioned in a complex section of floodplain, associated with the upstream section of the Deep Creek anabranch complex (Figure 5). A smaller high flow anabranch, which exits the Ovens River approximately 900m upstream of the weir threatens to capture a reduced length of the Ovens River (Figure 5). The Markwood Levee, (located on the opposite side of the floodplain to the Deep Creek anabranch complex) is also located adjacent to the weir. The levee intersects the Tea Garden Creek offtake. A penstock gate arrangement exists in the levee to regulate flows into Tea Garden Creek.

Figure 5 – Tea Garden Weir subject site (Source: Google Maps).

The Tea Garden Creek offtake arrangement was originally constructed in 1945 to deliver water to Tea Garden Creek for irrigation and stock and domestic purposes in the Markwood and Milawa area. The offtake consisted of a culvert and sluice gate arrangement to control the inflows to Tea Garden Creek. A channel was also constructed to connect the existing creek, near the Carboor-Everton Road to the offtake structure. The weir itself was subsequently constructed by the State Rivers and Water Supply Commission in 1968.

The Native Fish Strategy for the Murray – Darling Basin 2003 – 2013 (Murray – Darling Basin Ministerial Council, 2003) listed the Tea Garden Weir as one of 18 priority barriers requiring upgrading or new fish passage. Provision of fish passage through the Tea Garden Weir structure will allow fish passage through the Ovens River from the Ovens – Murray River junction, through to Porepunkah. Fishway designs were completed for the Porepunkah and Bright fish barriers in 2016.

3.2. Hydrodynamic Modelling

3.2.1. Overview

A hydraulic analysis was undertaken to accurately assess the hydraulic conditions surrounding the existing weir and assist in the detailed design of the fishway structure. The hydraulic flow characteristics (e.g. water depth and flow velocity) are critical in the determination of a suitable design arrangement that provides both low flows and fish passage through the weir. A partial width upstream rock ramp fishway structure was designed in this instance.

3.2.2. Model Setup

A detailed 2D hydraulic modelling approach was adopted for this study. The hydraulic modelling suite, TUFLOW, was used in this study. TUFLOW is a widely used hydraulic model that is suitable for the analysis of complex floodplain and hydraulic behaviour such as across the Ovens River floodplain in the vicinity of the weir and through the proposed fishway.

Two hydraulic models were set up to inform design of the weir and rock ramp fishway arrangement:

- A 2D floodplain model was developed to represent existing hydraulic conditions across the Ovens River floodplain in the vicinity of the weir and fishway. The floodplain model had a grid resolution of 5 metres. The model was run over the full range of likely flows. This model was then modified to simulate the effect of the new weir and fishway arrangement and associated topographic modifications on water levels and velocities in the Ovens River and floodplain.
- A more detailed 2D model was developed to model the hydraulic conditions within and around the fishway and weir itself (Figure 6), to ensure conditions were suitable for fish passage. The more detailed fishway model had a grid resolution of 0.25 metres which allowed the hydraulic conditions within the chute, including between the baffles, to be accurately understood. The detailed fishway model was used to model a range of flow rates until the weir was drowned out, which occurs at around 4,000 ML/d.

3.2.3. 2D Fishway Hydraulic Model

The proposed weir and fishway model was set up based on the preferred conceptual fishway design arrangement and through extensive input from the project team, including the Fish Ecologist. Numerous iterations were tested until the hydraulic requirements were met for fish passage. The final configuration has the following key attributes:

- A 48 metre long, partial-width rock ramp fishway, incorporating a four metre base width and 2(H):1(V) batter slopes.
- The rock ramp fishway is designed with a 40(H):1(V) longitudinal slope, with the upstream invert at 168.3m AHD (300mm lower than current temporary crest level) and downstream invert of 167.1 m AHD. This represents a drop of 1.2 metres through the ramp.
- The partial-width rock ramp and rock apron incorporates concrete baffles. The baffles are an important design element and have been designed and tested to provide favourable flow conditions (water depths, flow velocities and turbulence) for fish to approach and enter the fishway. The baffle arrangement consists of:
    - 13 rows of baffles through the partial-width rock ramp fishway, spaced 4m apart. The baffles are 0.5m wide by 0.5m long. The baffle spacing is 0.25m on the outer (lateral) thirds of the ramp and 0.5m through the centre of the chute.
    - Eight rows of baffles through the flat rock apron, spaced 4m apart. The baffles are 0.5m wide by 0.5m long. The baffle spacing is consistently 0.5m across the apron.
- The retention of the western half (approximately) of the existing weir arrangement, including the drop board and walkway.

The model DEM incorporated the fishway design arrangement is illustrated in Figure 6.

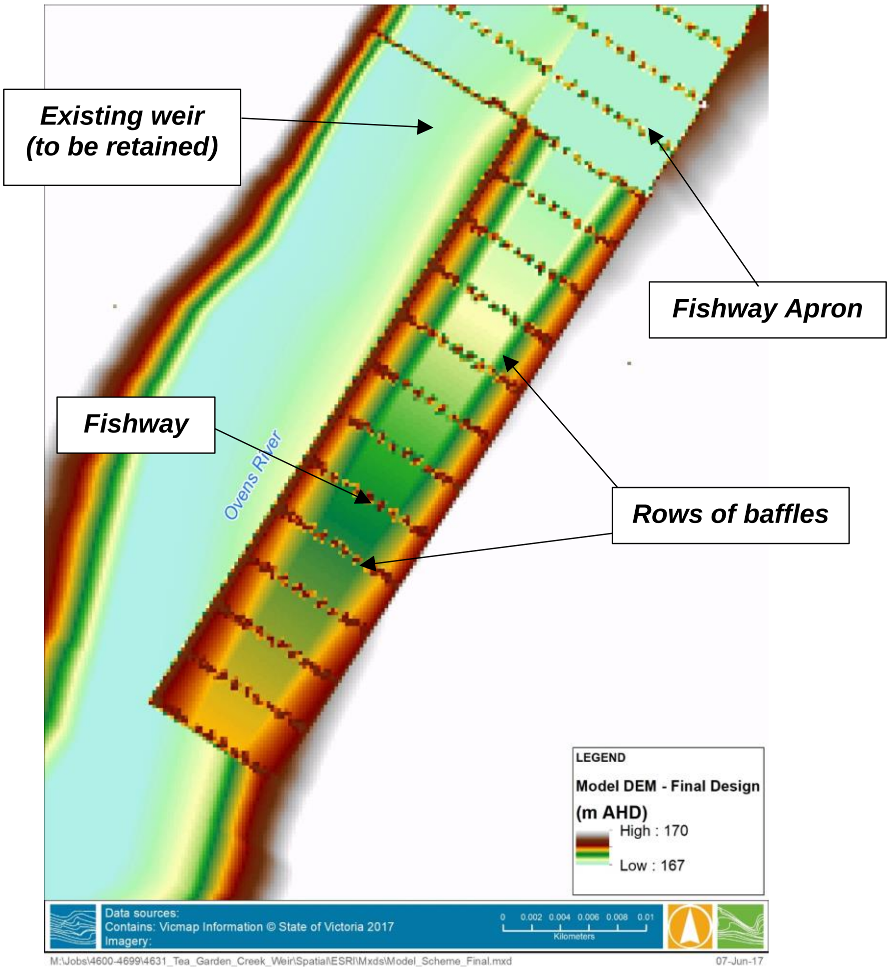

Figure 6 Tea Garden Fishway Model Bathymetry

3.2.4. Hydraulic Criteria

A range of small (i.e. Obscure galaxias), medium, and large sized (i.e. Murray cod) fish were identified in the Ovens River within the vicinity of Tea Gardens weir. Therefore, the fishway was designed to pass these size-classes during the key movement period (spring-autumn). The hydraulic modelling was undertaken to demonstrate the fishway design met the hydraulic criteria required to facilitate fish passage. The hydraulic criteria were provided by the project Fish Ecologist and are summarised as follows:

- Velocities to be generally less than 1.0 m/s through the fishway and entry/exit and ensuring that there is passage available through the ramp where velocities greater than 1 m/s do not exceed a longitudinal distance of 1 metre.
- Minimum depths of 0.5 metres to be achieved throughout the fishway across all applicable flow rates.
- Fishway slot widths of 0.5m through the majority of the structure to allow for passage of large Murray cod and narrower slot widths of 0.25m at the margins of the fishway for passage of smaller-sized species.

The modelling results presented below demonstrate that the hydraulic criteria have all been met with the recommended fishway design.

3.2.5. Hydraulics Results

Numerous fishway iterations were tested to ensure the hydraulic conditions described above were met, as well as required conditions regarding extraction of flows into Tea Garden Creek. An example of modelling results at a flow rates 180 ML/d is presented in Figure 7 below. The modelling results have demonstrated that:

- Velocities generally do not exceed 1 m/s for flow rates of up to and including 4,000 ML/d through the fishway and within the upstream and downstream approaches. Some small pockets of velocities more than 1 m/s occur, primarily between the baffles, but they extend for no more than 0.5 metres of longitudinal distance at low flow rates and 1-2 metre of longitudinal distance at higher flow rates. At high flow rates the larger pockets of high velocities can be avoided and the majority of the fishway has lower velocities that will facilitate fish passage.
- The results demonstrated that a minimum of 0.5 metres water depth has been achieved throughout the fishway across all flow rates. The shallowest depths occur in the lowest flow rate of 180 ML/d with depths of 520-530mm occurring through the upstream invert of the fishway.
- The concept design includes baffles with spacing of 0.5 metres through the centre third of the chute and 0.25 metres through the outer thirds of the chute. This has ensured the requirements regarding the passage of both small and large bodied species has been met.

In summary, extensive hydraulic modelling has been undertaken which has demonstrated that the recommended fishway design met the specified hydraulic criteria across the range of applicable flow rates.

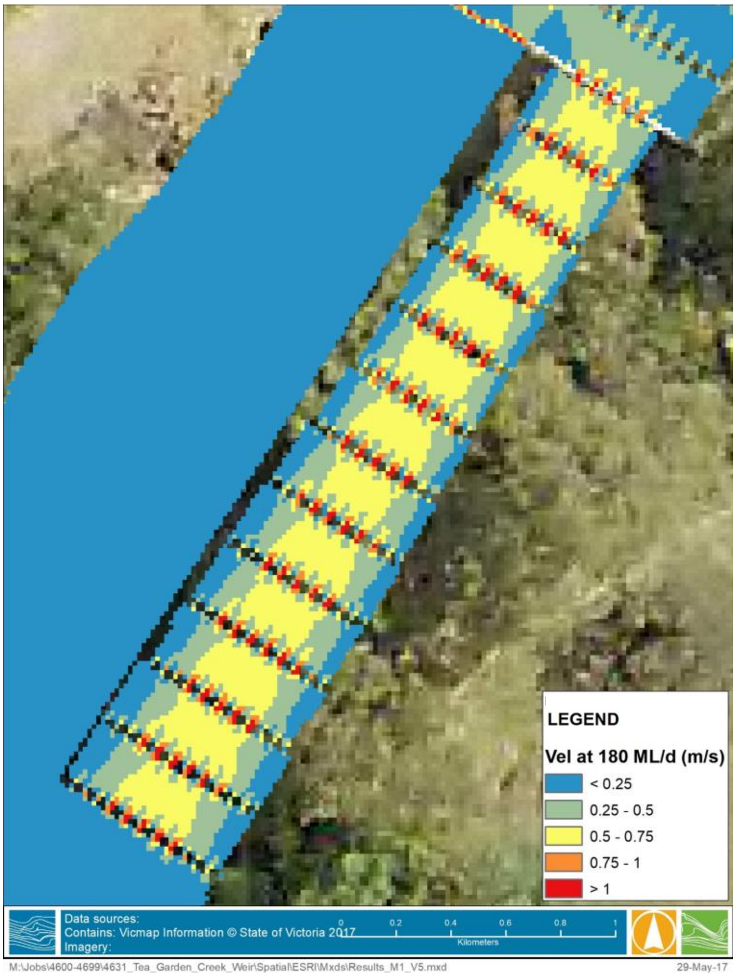

Figure 7 – Modelled fishway velocities at low flow of 180 ML/d

4. DISCUSSION AND SUMMARY

The selection of an effective fishway arrangement is dictated by any number of influences at any one site. This includes (but is not limited to) the existing weir characteristics and function, vehicle and plant (construction) access, cultural heritage, environmental assets, geomorphology (e.g. stability), fish passage requirements (e.g. target fish species hydraulic requirements), surrounding land uses, construction costs and stakeholder objectives. On this basis, a number of key technical specialists contributed to the site investigation, selection of a preferred design arrangement and detailed design.

2D and 3D hydrodynamic modelling are highly useful tools to inform and optimise fishway design. Both 2D and 3D modelling can be appropriate choices for informing fishway design and each have advantages and disadvantages. Key advantages of 2D modelling are that it's typically quicker to establish the model and model run-times tend to be shorter. This means project time frames are typically shorter and budgets lower for such modelling. Limitations are that the modelling does not consider the vertical distribution of velocities and turbulence.

3D hydrodynamic modelling is typically more complex and time-consuming to set up but offers advantages in that it fully resolves the vertical distribution of velocities and turbulence which can be an important advantage, particularly in vertical slot fishways where individual slot widths often vary in width. (Arrowsmith and Zhu 2014). This allows the full spatial distribution of these outputs to be understood. In the case studies above 2D modelling was an appropriate approach for the Tea Garden Weir fishway given a rock ramp/chute is proposed whilst 3D modelling was a more appropriate choice for the Snowy Creek fishway given a vertical slot fishway is proposed. There are numerous examples of where fishway structures have failed either through poor design or under design. Detailed hydrodynamic modelling provides a vital tool in ensuring a robust fishway design and ensuring the required structural integrity and design life spans are met.

This paper has presented two case studies of fishway design projects in North-East Victoria undertaken in partnership with North-East Catchment Authority and Arthur Rylah Institute, where detailed 2D and 3D hydraulic modelling has been utilised to improve and optimise the design of the fishway arrangement. One of the case studies involved the design of a partial width rock ramps/chutes while the other involved the design of a vertical slot fishway. Each location posed specific design challenges which were able to be overcome through the use of innovative fishway design and detailed modelling. Key outcomes of these projects are that fish passage will be markedly improved in the Ovens River and Snowy Creeks through fishways designed with the use of innovative, hydraulic modelling. These case studies demonstrate that detailed hydraulic modelling is a valuable tool used to support the design of new fishways to ensure the constructed fishway provides acceptable hydraulic conditions to facilitate fish passage.

5. ACKNOWLEDGMENTS

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