Modelling Physical Habitat Availability for the River Blackfish *(Gadopsis marmoratus)* in the Upper Yarra River, Australia

Bachelor Thesis

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Date
30/06/2017

Contents

Abstract

The physical habitat availability is simulated for the River Blackfish *(Gadopsis marmoratus)* in the upper Yarra River, Victoria, Australia. A part of a reach of the Upper Yarra River was selected as study area and the physical characteristics of the river such as cross sections, flow velocities, bed roughness and channel index were identified. The habitat suitability criteria for three life stages of the River Blackfish were also identified. Physical Habitat Simulation (PHABSIM) was used to simulate the flow versus the physical habitat availability for each life stage.

This research examines if the current environmental low flow in the upper part of the Yarra River -identified as Reach 1- is adequate for the River Blackfish to complete its life cycle. In this way, this research will contribute to the debates on the environmental flows, more specifically, about the physical habitat availability for the River Blackfish.

The results from the PHABSIM simulation is the weighted usable area of the River Blackfish in Reach 1 of the Yarra River at different life stages. The results show that the physical habitat availability for the River Blackfish is maximal at a discharge of 10Ml/day. The physical habitat availability for the immature and juvenile River Blackfish is maximal at a discharge of 4.3Ml/day

The amount of environmental low flow determined by Melbourne Water is an adequate amount of flow considering the adult River Blackfish. Considering the immature and juvenile River Blackfish current environmental low flow is too high. Melbourne water should reconsider the flow releases from October to January, which is the spawning season of the River Blackfish. A lower flow during this season will result in more physical habitat availability for the juvenile River Blackfish, which will contribute to its development.

1 Introduction

Increasing human water demands create conflict between the development of rivers as water resources and their conservation as integrated ecosystems (Tharme, 2003). It is widely accepted that human water demands must be balanced with the needs of rivers, but the tension in water resource allocation are intensifying (Ayllón, Almodóvar, Nicola, & Elvira, 2012). This is because of the growing human demand and uncertainties in the water needs of riverine ecosystems under climate change (Ayllón, Almodóvar, Nicola, & Elvira, 2012). This increasing water demand has facilitated the global expansion of dams, with river regulation acknowledged as the leading cause of biodiversity decline in rivers (Todd, Lintermans, Raymond, & Ryall, 2017).

Governments and water management authorities across the world have made significant and wide spread progress in developing policies and laws to recognise environmental flow needs (Le Quesne, Kendy, & Weston, 2010). The withdrawal of water from ecosystems can result in there no longer being enough available flow to support freshwater plants and animals. Freshwater plants and animals have evolved with, and intimately depend upon, natural patterns of hydrologic variability. Naturally high and low water levels create habitat conditions essential to the reproduction and growth of freshwater species, and drive ecological processes required for ecosystem health. The water flows and level that support these processes are termed "environmental flows" (Le Quesne, Kendy, & Weston, 2010).

Like many jurisdictions around the world, in the state of Victoria, Australia there is an increasing awareness in water resource management of the need to incorporate the environmental requirements of ecosystems into the water resource planning process. The determination of environmental water requirements is thus a key part of the water resource planning process (Sinclair Knight Merz and Melbourne Water, 2005).

More than 200 different methodologies have been described around the world to determine environmental flows. These methods can be categorized into four main types: hydrological, hydraulic rating, habitat simulation and holistic methodologies (Tharme, 2003). My research uses the PHABSIM software, which is part of the IFIM methodology to simulate the physical habitat availability of the River Blackfish *(Gadopsis marmoratus)* in Reach 1 of the Yarra River. IFIM is considered as a scientifically and legally defensible habitat simulation methodology available for environmental flow assessments, specifically the phase of IFIM that includes the habitat simulation, based on hydraulic simulation (da Costa, et al., 2015).

The Yarra River is located in the south-east of Australia (Figure 1.1). The flows in the Yarra River are regulated by Melbourne Water, the statutory authority that controls Melbourne's water supply, through many dams and reservoirs (Sinclair Knight Merz and Melbourne Water, 2012). Environmental flows for the Yarra River were determined using the FLOWS method. The FLOWS method is a holistic approach for assessing the flow requirements for the freshwater reaches of a river system. Sufficient information and expertise must be available on hydrology, geomorphology and ecology, before specific environmental objectives can be determined. After the development of the environmental objectives the 1-dimensional hydraulic model HECRAS is used to inform flow recommendations, but these are ultimately determined through expert knowledge (The State of Victoria Department of Environment and Primary Industries, 2013).

This research uses a more in-depth physical habitat modelling process to examine whether the current environmental low flow in Reach 1 of the Yarra River, is adequate for the River Blackfish to complete its life cycle.

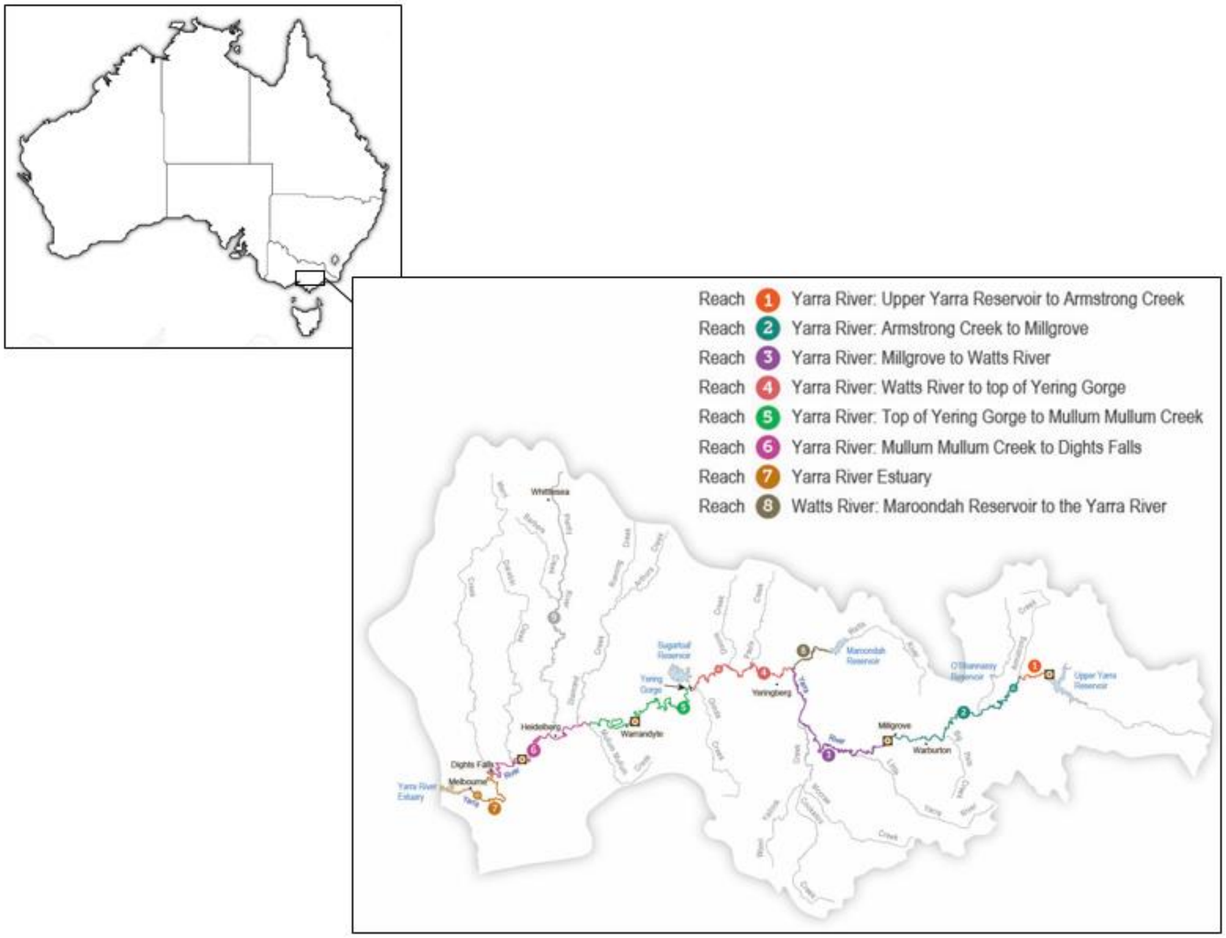

Figure 1.1: The Yarra River catchment, Reach 1 is shown in red. Reproduced from (Victorian Environmental Water Holder, 2016).

1.1 Literature review

Yarra River

The Yarra River flows from the Great Dividing Range to the east of Melbourne, to the end of its estuary at Port Philip Bay. The total catchment area of the river is 4044 km^2 and the river has a total length of 245 km (Adhikary, Yilmaz, & Muttil, 2015). The catchment of the Yarra River supports the drinking water resources used by Melbourne, the capital city of the state of Victoria. The upper reach of the Yarra River provides around 70% of Melbourne’s drinking water (Melbourne Water, 2016).

The Yarra River Catchment is divided into three zones: upper, middle and lower. This research will focus on Reach 1 (Figure 1.1), which is part of the upper reach of the Yarra River (Barua, Muttil, Ng, & Perera, 2013). Reach 1 of the Yarra River is relatively short (5 km) extending from the upper Yarra Dam to the confluence with Armstrong Creek - the first major tributary input to the Yarra River. The flows of Reach 1 have been fully regulated since the construction of the upper Yarra Dam in 1957 (Viggers, Weaver, & Lindenwayer, 2013). The environmental flows, determined by Melbourne water and Sinclair Knight Merz for Reach 1 are shown in Table 1.1.

Table 1.1: The environmental flow recommendations of Reach 1 of the Yarra River (Sinclair Knight Merz and Melbourne Water, 2012).

	Flow (Ml/day)	**Flow (m^3/s)**	**Frequency**
Summer/winter low flow	10	0.126	Minimum all year
Summer/autumn high flow	60	0.694	4 times every year
Winter/spring high flow	100	1.157	3 times every year
Winter/spring high flow	300	3.472	1 time every 2 years

Study area

This research focusses on a 230 m stretch of Reach 1 of the Yarra River. This area was selected based on relevance, available information and access and wadeability of the river. Part of the study area overlaps with the study area of Melbourne Water and Sinclair Knight Merz (2012). In this way, the results of the two studies can easily be compared. As earlier stated, Reach 1 is fully regulated, so adjustments in the flow can be made when desired. The study area was located approximately 3 km downstream of the dam wall and the gauge for compliance purpose is located downstream of the Doctors Creek confluence. Reach 1 of the Yarra River is in the beginning of the Yarra Catchment downstream of the dam, and so the instream flow is relatively low and the water is wadeable. The study area consists of deep pools, islands and riffles. The study area consists of some meander bends, but also has some straight sections. The density of vegetation is high and there are trees growing within the river channel. These different components mean that this part of the river is representative of the remainder of Reach 1 of the Yarra River.

The current environmental low flow for Reach 1 is 10 ML/day, which is relatively small compared to the other reaches of the Yarra River (Figure 1.2). An environmental flow assessment in the Little Forest River in Tasmania supports the inappropriateness of this low flow: it concluded that the River Blackfish is out of risk at flows higher than 14.7 Ml/day (Nelson, 2000).

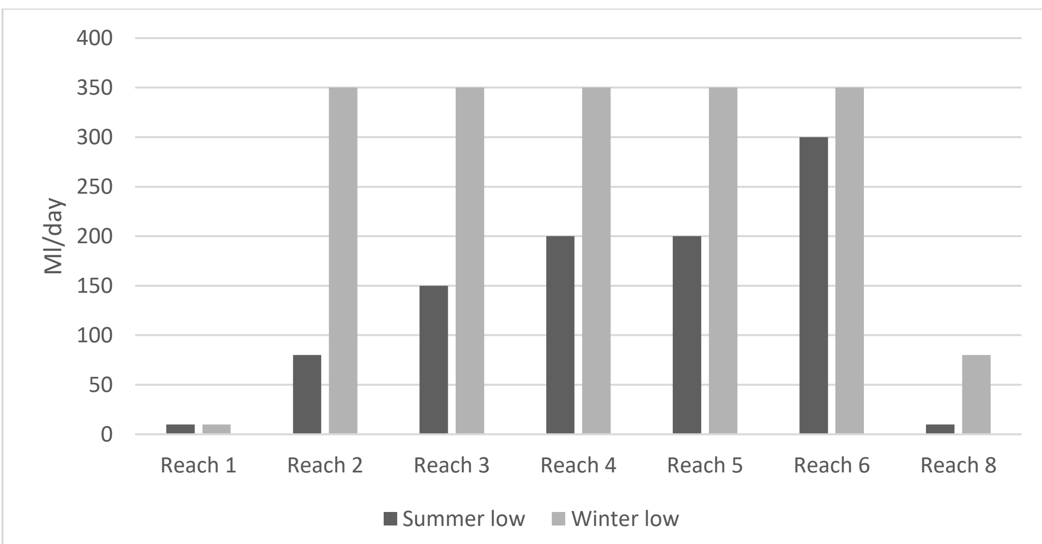

Figure 1.2: The environmental flows for summer and winter in the different reaches of the Yarra River (Sinclair Knight Merz and Melbourne Water, 2012).

River Blackfish

One of the objectives of Melbourne Water for Reach 1 of the Yarra River is to rehabilitate native fish community and abundance (Sinclair Knight Merz and Melbourne Water, 2005). The most common fish species in Reach 1 of the Yarra River are River Blackfish, Spotted Galaxias, Common Galaxias, Australian Grayling and Tupong (Sinclair Knight Merz and Melbourne Water, 2005). This research uses the River Blackfish (Figure 1.3) as target species in order to determine the environmental flows for Reach 1 of the Yarra River.

Figure 1.3: A picture of an adult River Blackfish in the study area (April 20,2017).

To select the target species, it is common to prefer the lager species that demand the most habitat, with low resilience and at a high level in the food chain. The protection of such "umbrella" species is thought to benefit many other species sharing the same habitat (Garcia-Rodriguez, Ochoa-Franco, & Cervantes-Servin, 2015). The River Blackfish is the largest fish species in Reach 1 of the Yarra River (Table 1.2) and the diet is carnivorous: a variety of insects, crustaceans, worms, small fish and fish eggs are ingested (Allen, Midgley, & Allen, 2003), this makes the River Blackfish the best option for target species.

Table 1.2: The length of the fish species, which are most common in Reach 1 of the Yarra River (Allen, Midgley, & Allen, 2003).

Fish Species	Length (cm)
River Blackfish	30
Spotted Galaxias	12-14
Common Galaxias	10
Australian Grayling	17-19
Tupong	15-20

The River Blackfish is a native species with a widespread distribution in the south-eastern Australia. However, the distribution of River Blackfish has been decreasing since European settlement (Westergaard & Ye, 2010). Freshwater Blackfish belong to a small family consisting of only two sub-species in the single genus Gadopsis: the Two-spined Blackfish *(Gadopsis bispinosus)* and the River Blackfish *(Gadopsis marmoratus).* The River Blackfish is a pale olive-green or brown to almost black fish, often with a diffuse marbled pattern. Maximum size is 350 mm, but is commonly 200-250 mm long and about 100 g. *Gadopsis marmoratus* has two sub-species: the northern and the southern, which mainly differ in maximum size (Lintermans, 2009). It prefers habitats with good instream cover such as woody debris, aquatic vegetation (Lintermans, 2009).

The decreasing abundance of the River Blackfish is mainly because of stream siltation, removal of woody debris and overfishing (Allen, Midgley, & Allen, 2003). The River Blackfish is sedentary, and remains within an approximate 20-30 m home range throughout its life span. This high fidelity for its home range means that the River Blackfish is highly susceptible to overfishing (Allen, Midgley, & Allen, 2003). For this reason, the River Blackfish is protected by Fisheries Management General Regulations 2007 under the Fisheries Management Act 2007 (Westergaard & Ye, 2010)

There is a range of native and exotic fish in Reach 1 of the Yarra River. However, the overall fish abundance is low, especially that of the River Blackfish, compared to similar streams nearby. Loss of habitat through smothering of benthic surfaces by sediment and sedimentation of pool habitat is likely to be the main contributor to reduced River Blackfish abundance in Reach 1. Cold water release from the Upper Yarra Reservoir may also impact on recruitment, with temperatures below 16 ℃ limiting the spawning potential of the species (Sinclair Knight Merz and Melbourne Water, 2005).

2 Research Aim, Questions, Objectives and Hypotheses

2.1 Research Aim

The aim of the research is to verify if the current low flow in Reach 1 of the Yarra River is adequate for the River Blackfish *(Gadopsis marmoratus)* to complete its life cycle. This will be done by simulating the physical habitat availability of the River Blackfish for different life stages, at different discharges in the study area.

2.2 Research Questions

The main question of this research is, whether the current minimum summer and winter flow of Reach 1 of the Yarra River adequate is for the River Black fish to complete its life cycle. This question can be answered by answering the following sub questions:

- Q1. What are the topographic and physical characteristics of the study area?
- Q2. What are the habitat preferences of the River Blackfish *(Gadopsis marmoratus)* at different life stages?
- Q3. How will physical habitat availability vary at different discharges?

2.3 Research Objectives

The determination of the physical habitat availability will be done by analysing the topographic surface and the physical characteristics of the riverbed of Reach 1 of the Yarra River (Section 3.2). The preferences of the River Blackfish relative to depth, velocity and channel index at different life stages will also be analysed (Section 3.3). This information will be used to calculate the physical habitat availability in weighted usable area of suitable habitat at different discharges. The weighted usable area will be calculated with the Physical Habitat Simulation (PHABSIM) software (Section 3.4 and Section 3.5). The optimal physical habitat availability will be compared to the physical habitat availability under the current low flow recommendations for summer and winter to assess the adequacy of these recommendations developed using the FLOWS method (Section 5).

2.4 Research Hypotheses

Considering the relative low environmental low flow in Reach 1 of the Yarra River and the results from the environmental flow assessment in the Little Forest River in Tasmania, which concluded that the River Blackfish is out of risk at a flow higher than 14.7 Ml/day, can be expected that the current low flow is not adequate for the River Blackfish to complete its life cycle.

3 Method

The physical habitat availability was simulated using PHABSIM, which calculates the weighted usable area of habitat. The physical habitat simulation consists of two parts: the hydraulic simulation and the habitat simulation. For the hydraulic simulation, river characteristics, such as the topographic survey of the study area, the value of Manning's n, the channel index, and the flow velocities of the river are needed. For the habitat simulation, habitat suitability criteria are needed for different life stages of the River Blackfish. The habitat suitability criteria (HSC) link the characteristics of a river to the habitat preference of the target species. The preference or suitability of the target species is described as a function of velocity, depth and channel index.

3.1 PHABSIM

PHABSIM is a collection of several sub-models developed by the U.S. Fish and Wildlife Service. The development started in the 1970's, and in 1984 the model was incorporated into computer simulation software (Pehrson, 2007). PHABSIM is a major component of the Instream Flow Incremental Methodology (IFIM), which is a conceptual framework that quantifies the effects of altered flow regimes on the aquatic biota of a riverine ecosystem (Midcontinent Edological Science Center, 2001). PHABSIM has been successfully used in other rivers, like the Lerma river (Garcia-Rodriguez, Ochoa-Franco, & Cervantes-Servin, 2015), the Atlantic Forest Stream (da Costa, et al., 2015) and the River Rällsälven (Pehrson, 2007). Overall, the IFIM methodology has the highest number of applications in the last decades worldwide, among the methods to assess environmental flows (da Costa, et al., 2015). However, it is much more resource intensive than the FLOWS method.

The basic idea of PHABSIM is rather simple. It assumes that fish abundance in a river is a function of the value of habitat in the river, with value of habitat being the product of habitat quantity and habitat quality. Habitat quantity is usually described as surface area of a section, and habitat quality is described is suitability or preference of the target species to the section (Sekine, 2012).

PHABSIM consist of two major simulations; the hydraulic simulation and the habitat simulation (Figure 3.1). The first step in the hydraulic simulation is determining the relationship between the water surface and discharge. The hydraulic modelling is 1-dimensional, and there are three methods for predicting the stage-discharge relationship: linear regression techniques based on multiple measurements from the field (STGQ model), use of Manning's equation (MANSQ model), and the calculation of water surface profiles using standard step-backwater computations (WSP model). There is also, one method for Velocity Simulation (VELSIM) (Midcontinent Edological Science Center, 2001). A description of the methods can be found in Appendix A: Terminology. For the habitat simulation, PHABSIM has only one method option: HABTAE. The HABTAE program is the standard program used for the habitat simulation and calculates the weighted usable area (WUA) in m^2 per 1000 m of channel. HABTAE uses the values of the Habitat Suitability Criteria (HSC) either directly measured by the researchers or drawn from existing literature, and links these to the values of depth, flow velocity and cover from the hydraulic simulation.

The hydraulic simulation, the habitat simulation and the methods are described in Figure 3.1. The thick grey lines in the figure describe the path this research followed and which methods were used.

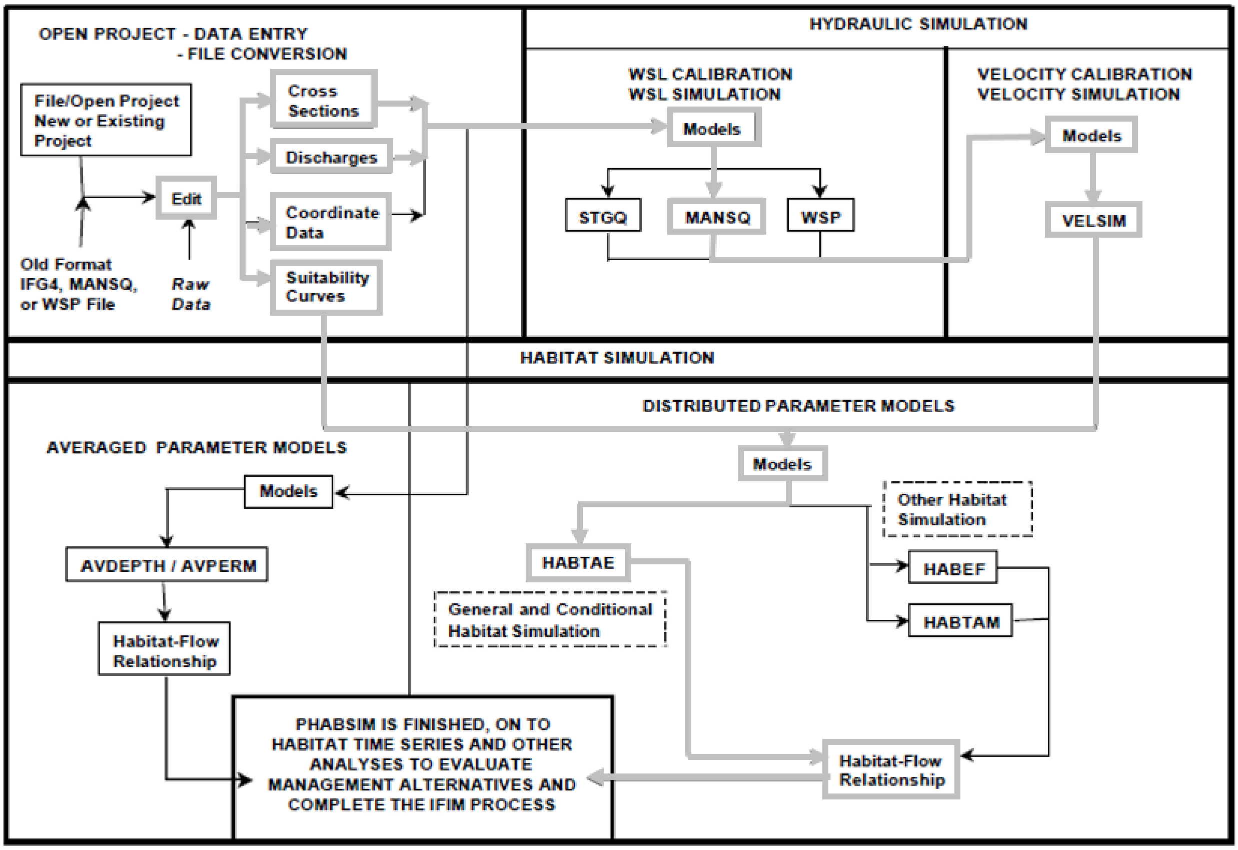

Figure 3.1:The flowchart of PHABSIM the grey lines show the path and the approaches this research used (modified from Midcontinent Ecological Science Center, 2001).

3.2 Topographic and Physical Characteristics

The characterizations of the physical features in Reach 1 of the Yarra River were collected through fieldwork. The topographic survey was performed using a Total Station, the value of Manning's n and the channel index were determined through observation of the river, and the flow velocities were measured using a flow meter.

3.2.1 Topographic Survey

The topographic survey is performed using a Sokkia Total Station, model SET5X (Appendix C: Devices). The total station is used because of its highly accurate measurements. The points within the measured a 3D hypervolume are accurate to a few 0.01 mm (Ehrhart & Lienhart, 2017). While creating the hyper-volume, the total station uses a laser to calculate the distance between its position and the prism. In this way, the total station can determine the cross-sectional characteristics and the distance and slope between multiple cross sections.

The beginning and the end of the study area were determined in advance, the cross sections were determined during the field trip, considering the following terms of reference:

- A cross section is surveyed approximately every 50 meters, when the river is straight and there are no noticeable changes.
- When the structure changes of the river occur (e.g. big pools or riffles), a new cross section needed to be surveyed.

- At a bend, a cross section must be surveyed at the beginning, middle and end of the bend.
- Cross sections must be made in a straight line, perpendicular to the thalweg.
- At every cross section, points must be measured inside the river, outside the river and at the water surface elevation.

During the fieldwork and data collection, Melbourne Water commenced an environmental flows release. This means that the flows differ from the normal low flow (10 Ml/day), see Table 3.1. At the first sampling occasion, seven cross sections were surveyed over a distance of 54 m and three flow velocity measurements were made. The average flow on that day was 15.85 Ml/day (as determined from the Melbourne Water gauge). At the second occasion, 12 cross sections were surveyed over a distance of 150 m. Three cross sections were surveyed at a flow of 21.41 Ml/day and nine cross sections were surveyed at a flow of 52.91 Ml/day. At the third occasion, four cross sections were made over a distance of 29 m and two flow velocity measurements were made. The average flow on that day was 53.24 Ml/day.

Table 3.1: The different flows during the sampling dates, according the Melbourne Water gauge.

Sampling dates	Time	Flow (Ml/day)	Flow (m^3/s)
11/05/2017	11:00-17:00	15.85	0.18
19/05/2017	9:00-11:00	21.41	0.25
19/05/2017	11:00-17:00	52.91	0.61
20/05/2017	09:00-12:00	53.24	0.62

3.2.2 The value of Manning's n and Channel Index

To simulate the physical habitat of the River Blackfish, the value of Manning's n is needed to characterize the roughness of the river, and the channel index is necessary to characterize the type of bed cover. Manning's n is a coefficient that indicates the resistance to flow or energy loss caused by the combined effects of particle size, vegetative friction, and channel features (Midcontinent Edological Science Center, 2001). It used in the hydraulic simulation of the water surface elevation. The channel index represents cover variables important in defining the physical habitat requirements of the target species. The River Blackfish is found in six types of cover habitats, see Table 3.2.

Table 3.2: The Channel Index categories (Koehn, 1986).

Category	Cover habitat
1	Undercut banks
2	Organic debris <50% density
3	Organic debris >50% density
4	Log jam <50% density
5	Log jam >50% density
6	Single log wood

During the fieldwork and data collection pictures and notes were made onsite for each cross section to determine the value of Manning's n and the channel index. The lower end of Reach 1 of the Yarra River is mostly covered in organic debris, the density of the organic debris is higher in the pools, so the channel index varies between 2 (is the shallow parts) and 3 (in the pools). Channel indices 4 and 5 represent logs above the water surface with a diameter greater than 250 mm. The density of the vegetation in the riverbanks is high, so the channel index for the riverbanks is set on 5. The pictures and notes can be found in Appendix B: Cross section Characterization.

3.2.3 Cross-Sectional Flow Velocities

Flow velocities were measured during the first and third field trip; this information was then used for calibrating VELSIM. The cross-sectional flow velocities and depths were measured at every 0.5m or when an apparent change in the river bed occurred (e.g. big rocks or vegetation that block the flow) (World Meteorological Organization, 2010). The velocity of the flow was measured with the hydrological OSS-PC1 Pygmy Current Meter (Appendix C: Devices). The measured flow velocities, the corresponding discharge, the discharge according to the gauging station and the associated cross sections are shown in Table 3.3.

Table 3.3: The measured flow velocities, the associated discharges and the discharge measured at the gauging station.

	Measured discharge (Ml/day)	Discharge according gauging station (Ml/day)	Average Measured Velocity (m/s)	Cross section
Field trip 1 (11/05/2017)				
- Road East	15.48	16.14	0.22	22
- Pool	16.69	16.14	0.11	18
- Island	16.23	16.14	0.19	16
Field trip 3 (20/05/2017)				
- Road East	52.80	53.99	0.35	22
- Road West	52.91	53.99	0.24	1

3.3 Habitat Preferences

The habitat preferences are described in habitat suitability criteria (HSC). The habitat suitability criteria link the characteristics of a river to the habitat preference of the target species. The preference or suitability of the target species is described as a function of velocity, depth and channel index. HSC values range from 0 to 1, with zero being unsuitable and one being most used or preferred (Midcontinent Edological Science Center, 2001).

Habitat Suitability Criteria assume that individuals of a species will tend to select the most favourable sites in a stream, but will also use less favourable sites with a lower probability. The suitability or preference of the target species is difficult to measure because it varies with the innate characteristics of each species (Koehn & Kennard, 2013). The preference of fish species also differs at different life stages. Many fishes need specialised nursery habitats to protect their early life stages; this may be related to competition, predator avoidance, trophic differences or physiological tolerances or morphological constraints (Koehn & Kennard, 2013). For this reason, different HSCs are needed for various life stages of the River Blackfish.

Some studies directly collect HSC data through snorkelling surveys (da Costa, et al., 2015). In this study, there was no opportunity to directly collect the HSC data, and so I employed data from previous studies.

Adult River Blackfish

I used HSCs for the adult River Blackfish determined in a 1986 study in nearby Armstrong Creek (Koehn, 1986) (Figure 3.2). Armstrong Creek is located 1.5 km northwest of the study area and is a tributary of the Yarra River. River Blackfish with a length more than 12 cm are classified as adults (Maddock, Thoms, Jonson, Dyer, & Lintermans, 2004).

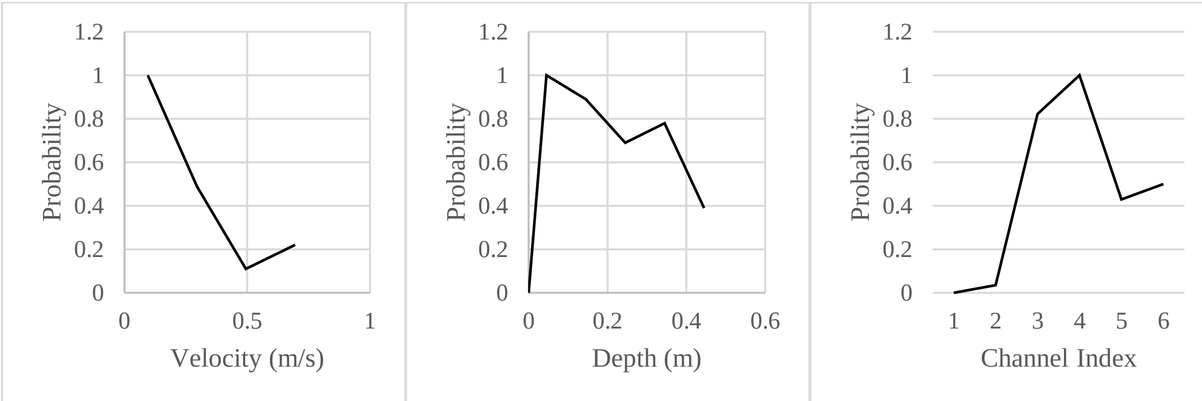

Figure 3.2:The Habitat Suitability Curves for the adult River Blackfish (Koehn, 1986).

Immature and Juvenile River Blackfish

For River Blackfish, HSCs were only available for adults, so I used HSCs from the Two-Spined Blackfish *(Gadopsis bispinosus)* for the life stages of immatures and juveniles (Figure 3.2 and Figure 3.3). Most of the ecology of the River Blackfish is similar to that of the Two-Spined Blackfish (Lintermans, 2009), and so the results of this study will be sufficiently accurate. The HSCs for the adult River Blackfish and adult Two-spined Blackfish are shown in Appendix D: Habitat Suitability Criteria to demonstrate their similarity. The HSCs of the Two-Spined Blackfish were developed from data collected as part of a previous study that described the water depth and water velocity present at fish capture locations (Maddock, Thoms, Jonson, Dyer, & Lintermans, 2004). Immature and juvenile Blackfish are distinguished through length: immature fish have a length between the 8cm and 11.9cm, and juveniles have a length less than 8cm.

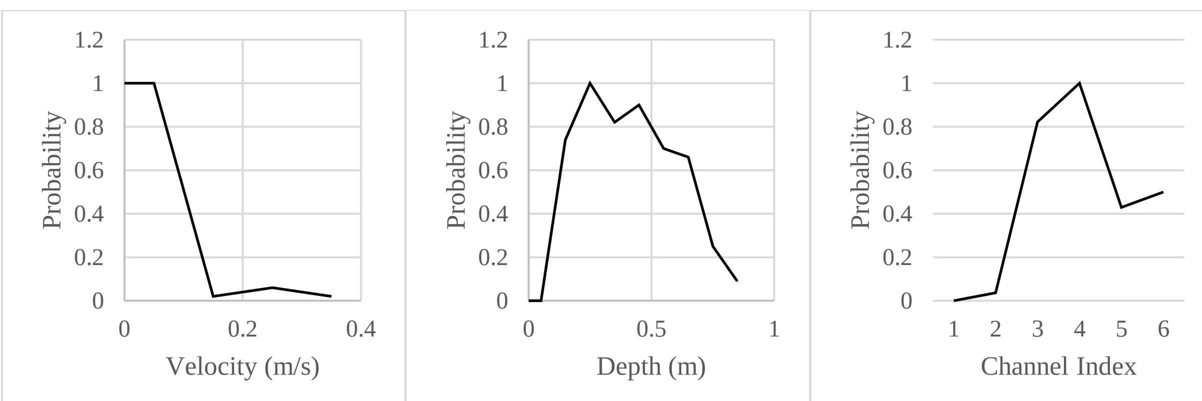

Figure 3.3: The habitat suitability curves for the immature Blackfish (Maddock, Thoms, Jonson, Dyer, & Lintermans, 2004).

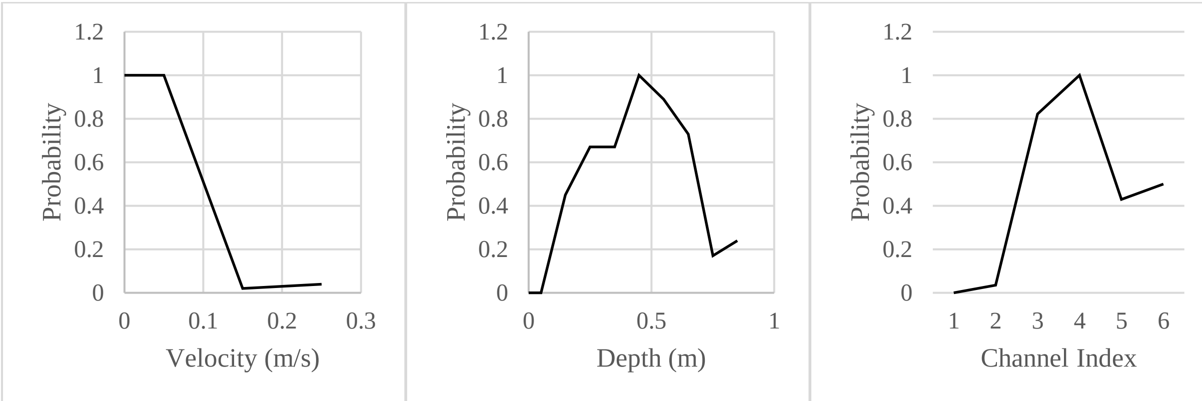

Figure 3.4: The habitat suitability curves for the juvenile Blackfish (Maddock, Thoms, Jonson, Dyer, & Lintermans, 2004).

Egg and Larvae River Blackfish

Spawning in River Blackfish occurs from October to January when water temperatures exceed 16°C (Allen, Midgley, & Allen, 2003). The spawning site is usually inside hollow logs, although rocks and undercut banks may also be used. The eggs are laid in areas where there is almost no flow. They are large approximately 4mm and hatch after 14 days with larvae about 6-8 mm long. The male guards and fans the eggs and rarely leaves the spawning site. The larvae remain at the spawning site for about three weeks after hatching. When the larvae leave the nest, they are quick and agile swimmers (Lintermans, 2009). For this reason, no separate HSCs are required for River Blackfish eggs and larvae (M. Lintermans, University of Canberra, pers. comm.).

3.4 Hydraulic Simulation

3.4.1 Water Surface Elevation

The first step in the hydraulic simulation is determining the relationship between the water surface elevation and discharge. This research used the MANSQ method for the simulation of water surface elevation.

MANSQ can simulate different water surface elevations for a cross section, when a measured discharge and water surface elevation are given for a cross section. STGQ and WSP need three discharges and water surface elevations per cross section to simulate other water surface elevations. Because of the available time, only one discharge and water surface elevation were measured for every cross section, so the water surface elevation was simulated using MANSQ method.

A general assumption for all the models is the equation of continuity:

$$Q = V * A \tag{3.1}$$

Q = instream flow (m^3/s)
V = Cross section mean flow velocity (m/s)
A = Cross section area (m^2)

The MANSQ method determines the stage-discharge relationship for every cross section individually. The uniform flow assumption allows the use of measured hydraulic slope instead of energy slope, since, by definition, they are equal in a uniform flow (Midcontinent Edological Science Center, 2001).

The MANSQ method uses the Manning's equation in the form:

$$Q = \left(\frac{{S_e}^{\frac{1}{2}}}{n}\right) * A * R^{2/3} \quad (3.2)$$

Q = Instream flow (m^3/s)
A = Cross section area (m^2)
R = Hydraulic radius (m)
S_e = Energy slope (m/m)
n = Manning's n value ($s/m^{1/3}$)

The water surface elevation is then determined using the cross section and the cross section area.

3.4.2 Calibration Water Surface Elevation

During the calibration of the water surface elevation, the measured water surface elevation and measured discharges were compared with the discharges according to the flow gauging station. There were five velocities/discharges measured during the fieldwork, see Table 3.3. The calibration will be done by adjusting β. β is a coefficient supplied by the user for each cross section.

The application of the MANSQ method and STGQ method can be problematic in pools; because these are created by the backwater effect. A backwater is an area of the stream where the water surface elevation is controlled by a hydraulic control. An example of a typical backwater area is a pool upstream of a riffle. The backwater effect causes unnatural high water surface elevations at pools, violating the continuity of flow assumption, this error also was corrected with β.

Equation 3.2 was simplified in the calibration to:

$$K = \frac{Q}{A * R^{2/3}} \quad (3.3)$$

Q = Instream flow (m^3/s)
A = Cross section area (m^2)
R = Hydraulic radius (m)
K = constant (s^{-1})

The value of K is determined from one set of measured discharge and water surface elevation pairs and measured channel geometry at each cross section. K is also used for the calibration of water surface elevation:

$$K = K_o * \left(\frac{Q}{Q_o}\right)^{\beta} \quad (3.4)$$

Q = Instream flow (m^3/s)
K_0 = Calibration value for K (-)
Q_0 = Calibration value for Q (m^3/s)
β = Calibration coefficient (-)
K = The variable from which the simulated water surface elevation is found (-)

When the β-coefficient increases, the water surface elevation decreases. So, the β of the cross sections with a too high simulated water surface elevation was decreased, and the β of cross sections with a too low water surface elevation was increased. I experimented with different values of β to obtain a satisfactory water surface simulation. β was varied between 0 and 0.6 until the difference between the measured discharge and the discharge according to the flow gauging station were minimalized and the high water surface elevations at the pool were corrected.

3.4.3 Simulation Discharges

When the water surface elevation was calibrated, the other discharges and the corresponding water surface elevations were determined, in order to compare the physical habitat availability at different discharges. Eight discharges and corresponding water surface elevations were simulated in PHABSIM: the four environmental flows shown in Table 1.1 (0.126 m^3/s, 0.694 m^3/s, 1.157 m^3/s and 3.472 m^3/s) and four flows in between the environmental flows (1.0 m^3/s, 1.5 m^3/s, 2.0 m^3/s and 3.0 m^3/s) in order to determine a sound weighted usable area versus discharge graph.

3.4.4 Velocity Simulation

The next step of the hydraulic modelling within PHABSIM involves simulating velocity profiles at each cross section of the river. The simulation of the velocity is done with VELSIM.

The velocity is simulated with:

$$V_i = \frac{S_e^{1/2} d_i^{2/3}}{n_i} \qquad (3.5)$$

n_i = Manning's n at vertical i ($s/m^{1/3}$)
S_e = Energy slope (m/m)
d_i = Depth at vertical i at calibration discharge (m)
v_i = Velocity at vertical i at calibration discharge (m/s)

3.4.5 Calibration Velocity

The calibration of the flow velocity is done adjusting the value of Manning's n in different parts of a cross section. First, cross sections 1, 16, 18 and 22 were calibrated, using the flow velocity data (Table 3.3), and by varying the value of Manning's n between 0.020 and 0.100.

The values for the Manning's n for the riverbeds of the other cross sections were determined using the data cross sections 1, 16,18 and 22, and the values of Manning's n determined in Appendix B: Cross section Characterization. Cross sections 1 and 22 were situated on causeways, cross section 16 in a riffle and cross section 18 in a pool. Therefore, the values of Manning's n for the other cross sections on causeways were determined using cross section 1 and 22, and similarly for other types of habitat.

Figure 3.5: A picture of the riverbed and the riverbank. The vegetation on the riverbank is high and has a Manning's n value of 0.150.

The calibration of cross sections 1, 16, 18 and 22 indicated a Manning's n value of 0.150 for the riverbanks. The border between the riverbed and riverbank is clear because of the regulated flow (Figure 3.5), so the Manning's n value above the water surface elevation (at a discharge of 10 Ml/day) was set at 0.150.

3.5 Habitat Simulation

The HABTAE program is the standard program used for the habitat simulation and was used to calculate the weighted usable area (WUA) in m^2 per 1000 m of channel. HABTAE assumes that (Midcontinent Edological Science Center, 2001):

- Individual organisms select the most desirable conditions within a stream.
- Desirable conditions can adequately be represented by habitat suitability criteria.
- Each cell can be evaluated independently and that the WUA in each cell is indicative of total habitat conditions at a specific discharge.

HABTAE uses the suitability index values derived from each cell in a transect for depth, velocity, and channel index:

$$\text{WUA} = \sum_{i=1}^{n} A_i * C_i \qquad (3.6)$$

WUA = Weighted Usable Area in a stream at specified discharge of cell i (m^2)
A_i = Surface area of cell i (m^2)
C_i = Composite suitability of cell i (-)

The combined suitability is derived from the component attributes of each cell, which are evaluated against the species specific life history stage HSC coordinates for each attribute to calculate the component suitabilities (Figure 3.6):

$$C_i = V_i * D_i * S_i \qquad (3.7)$$

C_i = Composite suitability of cell i (-)
V_i = Suitability associated with velocity in cell i (-)
D_i = Suitability associated with depth in cell i (-)
S_i = Suitability associated with channel index in cell i (-)

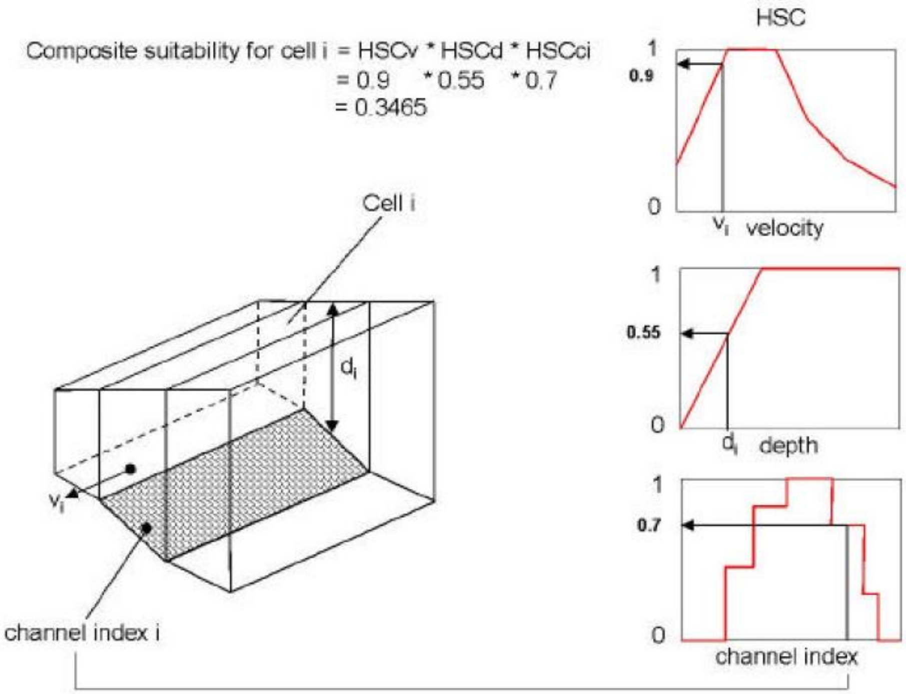

Figure 3.6:Habitat suitability criteria attributes for a habitat cell (Midcontinent Edological Science Center, 2001).

The WUA for every cell at every cross section are summed to get the total WUA of a cross section and the WUA of all the cross sections are summed to get the total WUA of the study area.

4 Results

4.1 Results Topographic and Physical Characteristics

4.1.1 Topographic Survey

The 22 surveyed cross sections are shown in Figure 4.1. In PHABSIM, the first cross section needs to be the cross section downstream the study area. So, cross section 1 (Figure 4.1) is the most downstream cross section.

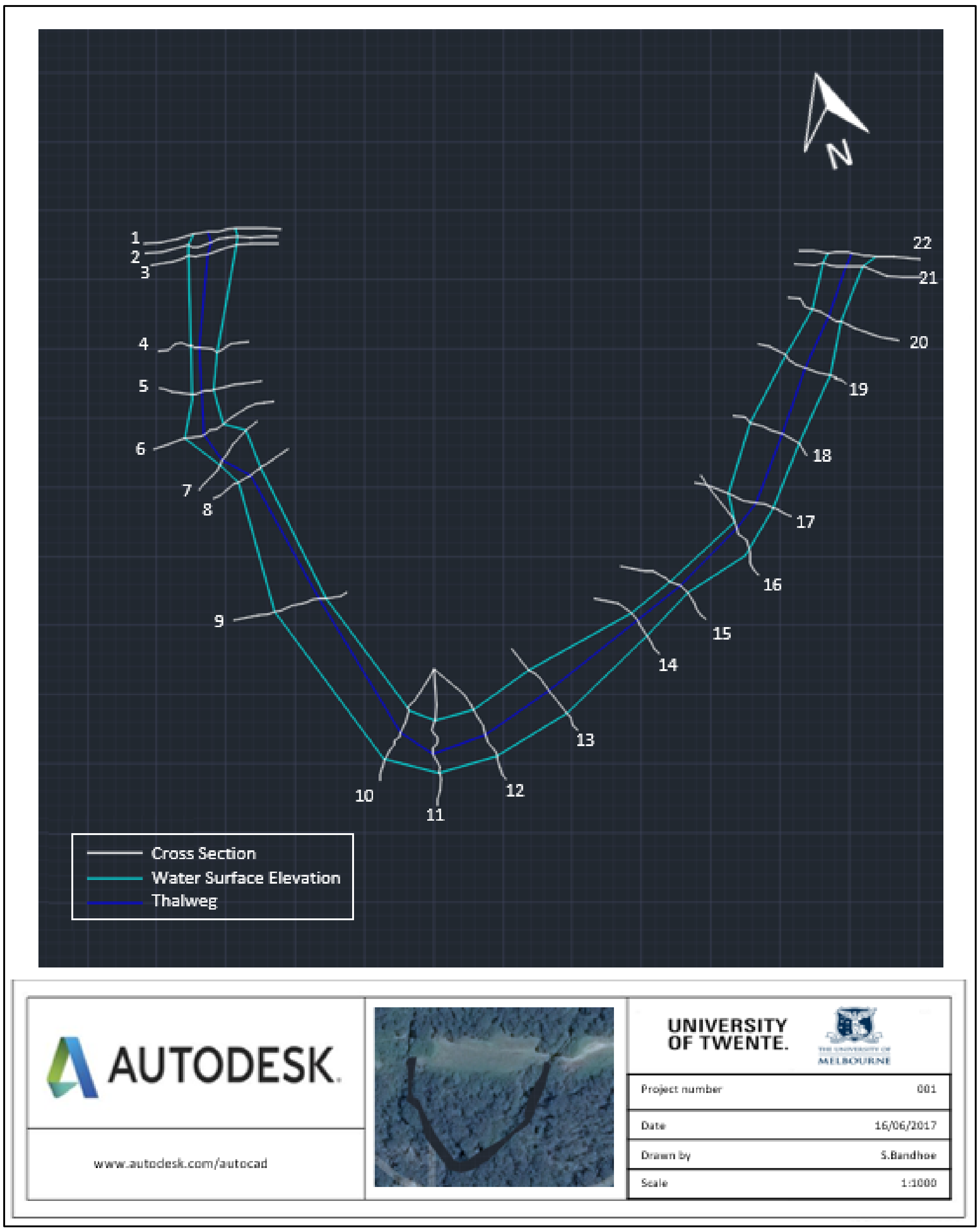

Figure 4.1: The result of the topographic survey. The 22 cross sections in white, the thalweg in dark blue and the water surface elevation in light blue.

4.1.2 The value for Manning's n and Channel Index

The detailed estimation of Manning's n values and channel index values is provided in Appendix B: Cross section Characterization. The results are shown in Table 4.1.

Table 4.1: The value off Manning's n and the Channel Index.

Cross section	Manning's n value	Channel Index
1	0.03	2
2	0.03	2
3	0.03	2
4	0.03	3
5	0.03	3
6	0.045	2
7	0.045	2
8	0.045	2
9	0.060	2
10	0.03	3
11	0.04	3
12	0.04	3
13	0.03	3
14	0.03	2
15	0.04	2
16	0.05	2
17	0.03	3
18	0.03	3
19	0.035	3
20	0.035	3
21	0.03	2
22	0.03	2

4.2 Results Hydraulic Simulation

4.2.1 Results Water Surface Elevation

At the start of the calibration of the water surface elevation, the value of β was set to 0.2. Figure 4.2 shows the longitudinal profile at a β of 0.2. The longitudinal profile is a plot of the water surface elevation at each cross section within a reach versus the cumulative reach length (Midcontinent Edological Science Center, 2001). Figure 4.2 also shows the expected high-water surface elevations at the pools, caused by the backwater effect.

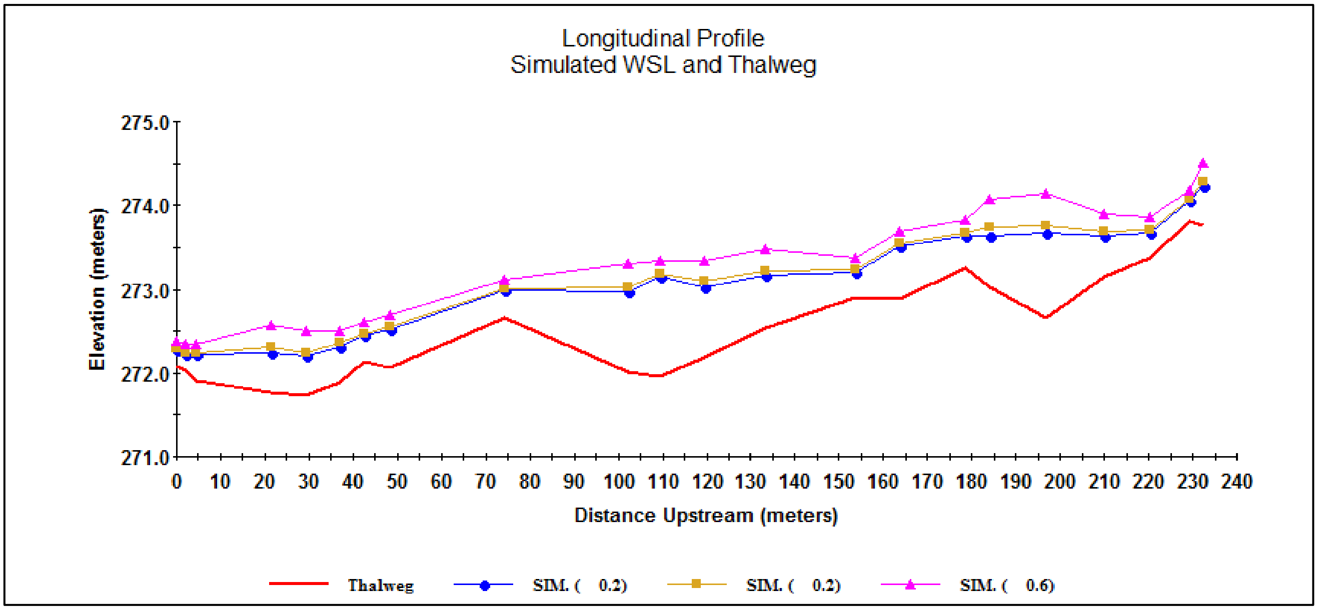

Figure 4.2: The longitudinal profile, including the thalweg and the simulated water surface elevations at a discharge of 0.187m^3/s, 0.247 m^3/s and 0.625 m^3/s. Before the calibration of MANSQ.

A longitudinal profile of the study area after the calibration of MANSQ is shown in Figure 4.3.

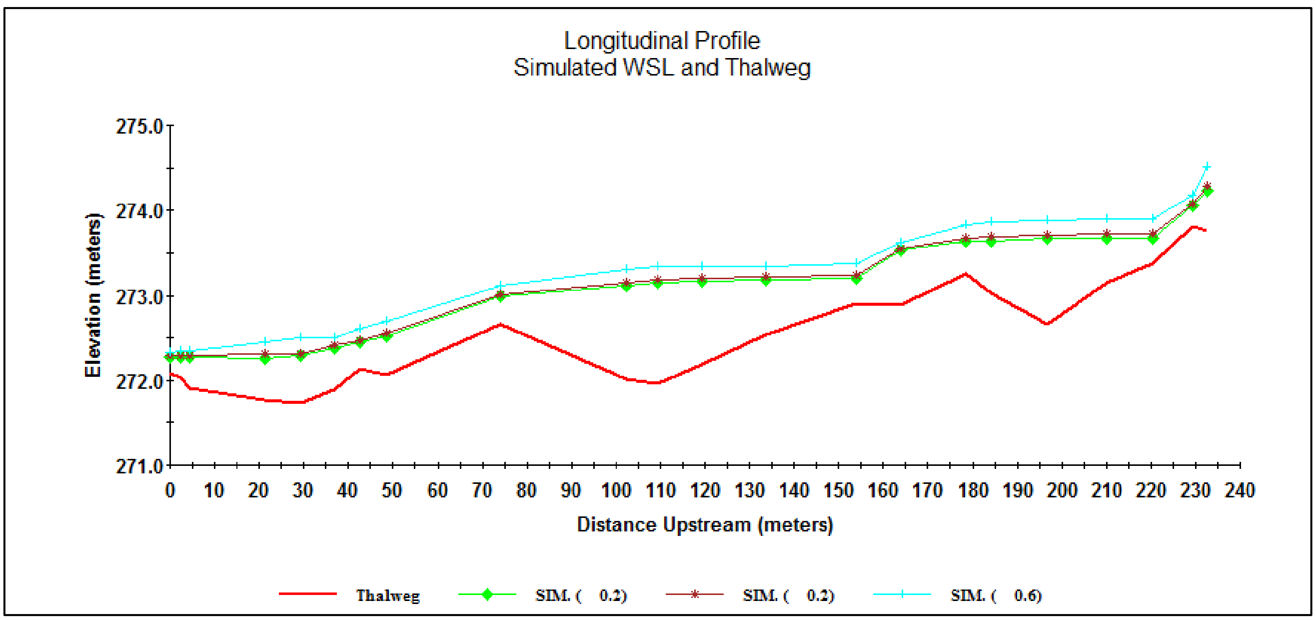

Figure 4.3:The longitudinal profile, including the thalweg and the simulated water surface elevations at a discharge of 0.187m^3/s, 0.247 m^3/s and 0.625 m^3/s after MANSQ calibration.

4.2.2 Results Water Elevation different Discharges

The water surface elevation of different discharges, including the environmental flows, were also simulated. The longitudinal profile is shown in Figure 4.4, showing clear differences in water surface elevation at different discharges. The Water Surface Elevation for every cross section at different discharges can be found in Appendix E: Water Surface Elevations and Flow Velocities.

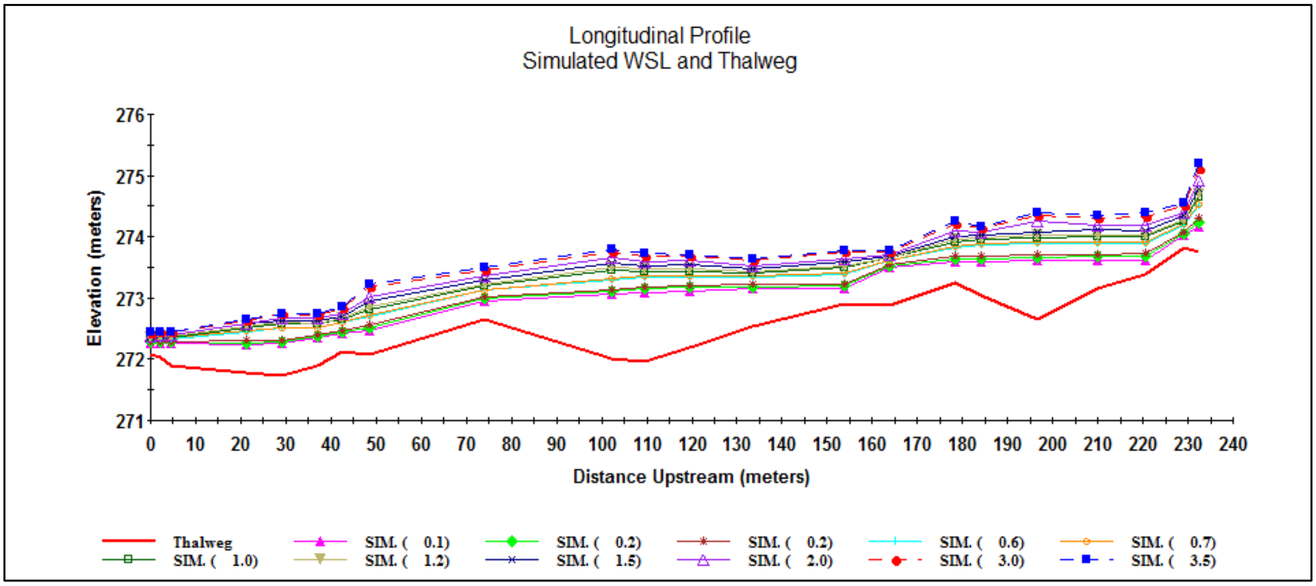

Figure 4.4: The longitudinal profile of the study area, including the thalweg, the simulated water surface elevations and the simulated water surface elevations at environmental flows. The discharges are 0.126 m^3/s, 0.187m^3/s, 0.247 m^3/s, 0.625 m^3/s, 0.694 m^3/s, 1.500 m^3/s, 2.000 m^3/s, 3.000 m^3/s and 3.470 m^3/s

4.2.3 Results Velocity Simulation

The flow velocities were simulated for every cross section. Examples of simulated flow velocity are shown in Figure 4.6 and Figure 4.6: cross sections 18 and 22 were calibrated with the flow velocity data and, cross section 4 and 15 were simulated without calibration data. The flow velocities for every cross section can be found in Appendix E: Water Surface Elevations and Flow Velocities.

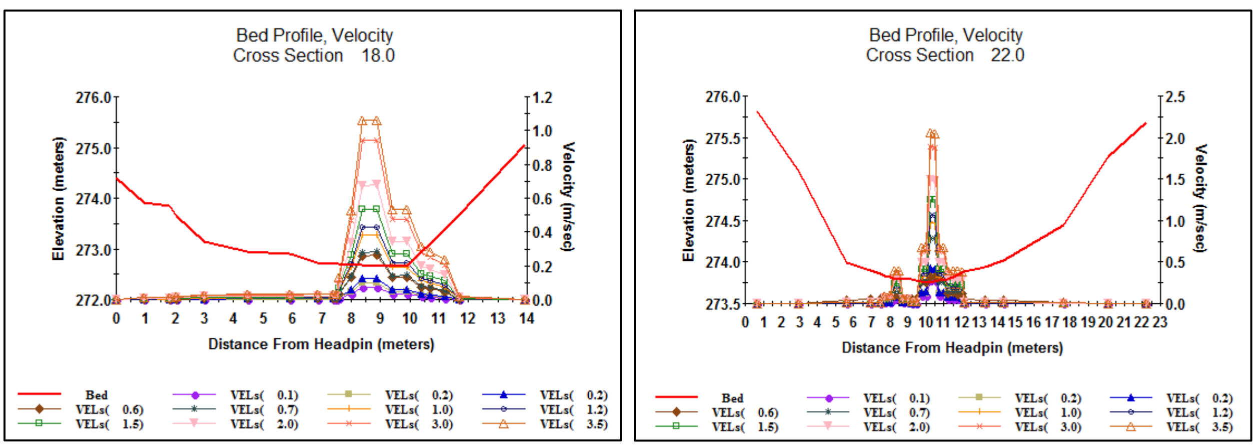

Figure 4.5: The flow velocities simulated at cross section 18 and cross section 22, at a discharge of 0.126 m^3/s, 0.187m^3/s, 0.247 m^3/s, 0.625 m^3/s, 0.694 m^3/s, 1.500 m^3/s, 2.000 m^3/s, 3.000 m^3/s and 3.470 m^3/s. These cross sections were calibrated with a flow velocity calibrations set.

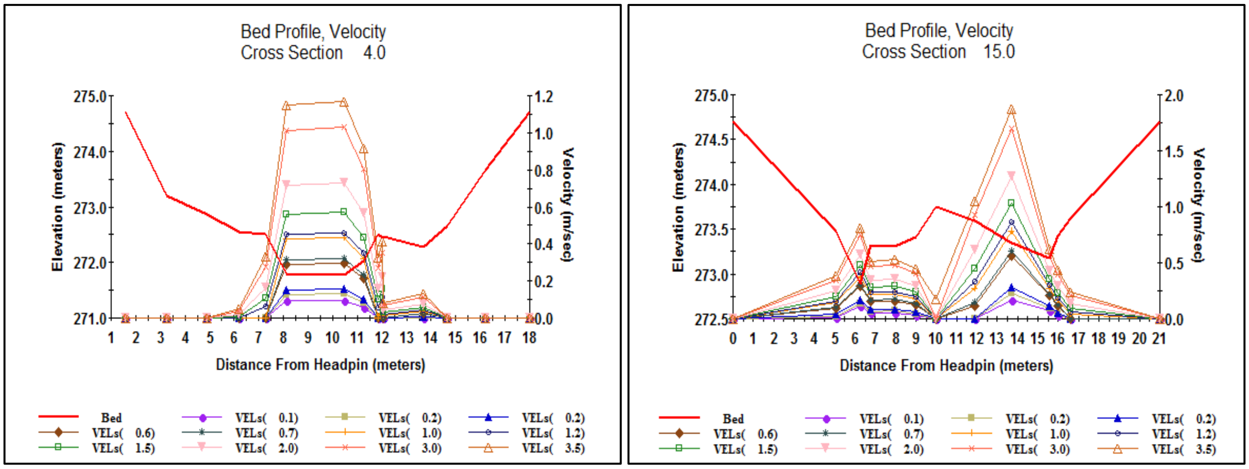

Figure 4.6: The flow velocities simulated for cross section 4 and cross section 15, at a discharge of 0.126 m^3/s, 0.187m^3/s, 0.247 m^3/s, 0.625 m^3/s, 0.694 m^3/s, 1.500 m^3/s, 2.000 m^3/s, 3.000 m^3/s and 3.470 m^3/s. These cross sections were simulated without calibration data.

4.3 Results Habitat Simulation: Physical Habitat Availability

PHABSIM calculated the combined suitability for every cell for every discharge and every life stage, see Figure 4.7. The total weighted usable area of a cross section is calculated by adding the weighted usable area of all the cells in a cross section.

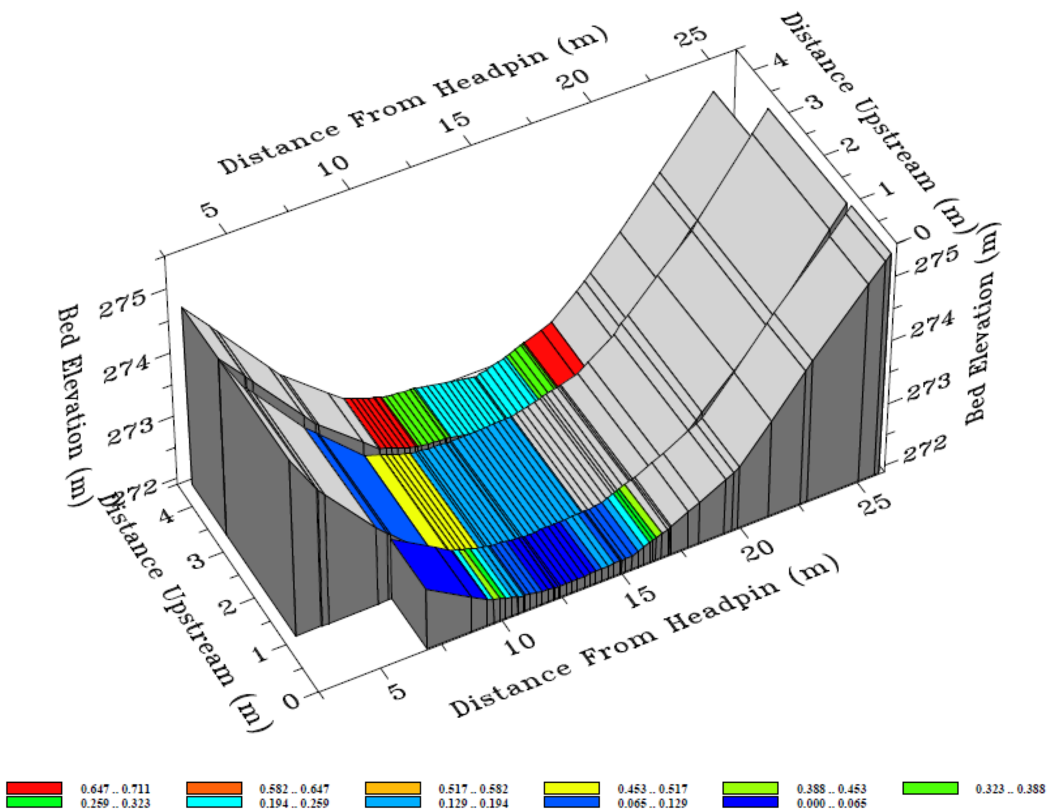

Figure 4.7: The combined suitability for every cell in cross section 1, 2 and 3 for the adult River Blackfish at a discharge of 0.63 m^3/s.

The total weighted usable area of the study area is calculated by adding all the WUAs of the cross sections. The length of the study area is 232.703 m, this length is multiplied by 4.29 to get the WUA per 1000 m. Figure 4.8 shows the weighted usable area per 1000 m.

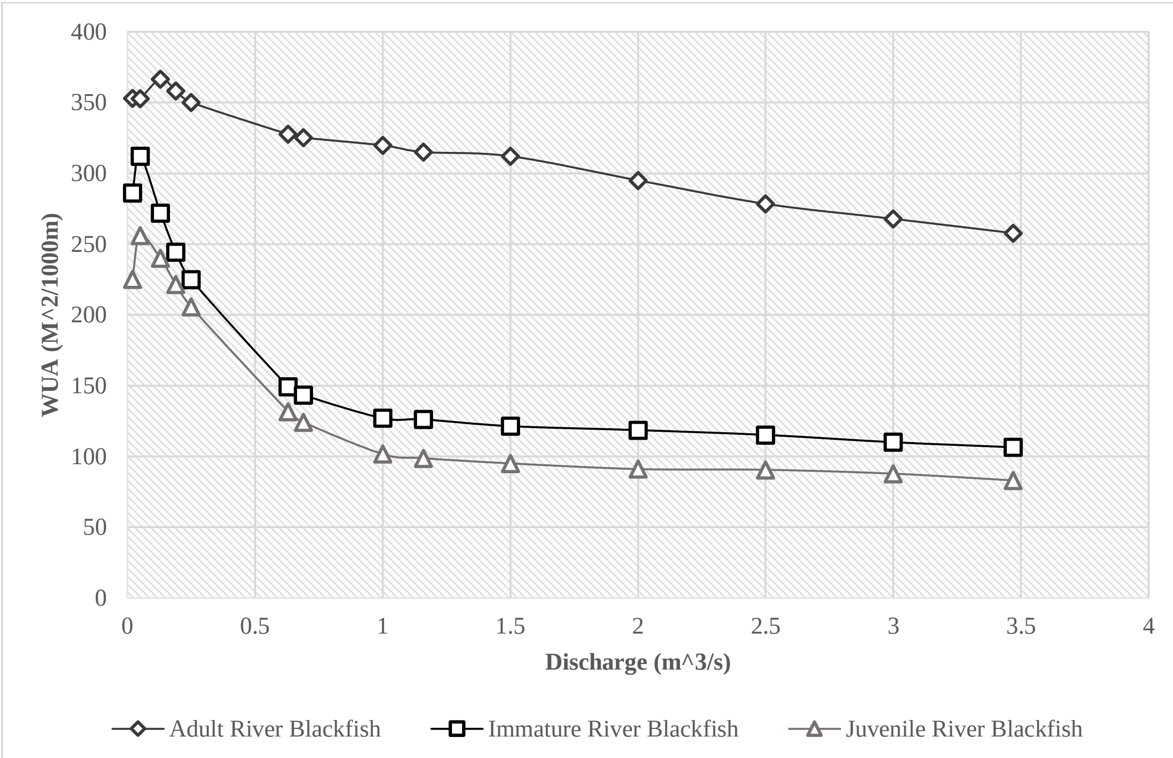

Figure 4.8: The Weighted Usable Area versus the discharge for the River Blackfish in Reach 1 of the Yarra River, at different life stages.

The optimal weighted usable habitat for the adult River Blackfish is 0.13 m^3/s, which is 10 Ml/day. The optimal weighted usable habitat for the immature and the juvenile River Blackfish is at a discharge of 0.05m^3/s (4.3 Ml/day).

5 Discussion

The PHABSIM analysis shows that the current environmental low flow of 10Ml/day is adequate for the River Blackfish to complete its life cycle. However, the optimal WUA for the immature and juvenile River Blackfish is at a discharge of 0.05 m^3/s (4.32 Ml/day). Figure 4.8 illustrates that WUA drops off quite quickly for immature and juvenile Blackfish even at quite low flows. The optimal physical habitat availability for all life stages of the River Blackfish is at a lower discharge than expected. This can be explained by the velocities and depths. When the discharge gets higher, the velocities also gets a lot higher in the river, because the riverbank is covered with highly dense vegetation. The high velocities in the river resulted in a low preference for the River Blackfish. The high discharges also cause the river to get deeper and the River Blackfish prefers pool smaller than 1m.

This research provides a conceptually finer-scale picture than the FLOWS method on environmental flows, because the physical habitat simulation considers different life stages. The discharge determined with the flows method is adequate for the adult River Blackfish, but lower flows at the right time of year would be better for juveniles and Immatures. So, it would be advisable to release less flow from October to January (spawning season), to create the maximal physical habitat availability for juveniles.

A lower release during the spawning season would allow Melbourne Water to held back environmental water. Over a period of four months, 5 Ml/day could be held back, which result in 600Ml that could be used for other purposes.

The simulated WUA of the River Blackfish in the Yarra River agree with the results of environmental flow assessment performed in the Little Forester River in Tasmania which was simulated with the RHYHAB software (Figure 5.1) (Nelson, 2000). Both Figure 4.8 and Figure 5.1 show a peak in WUA for River Blackfish at relatively low flows. Differences between the results of the two rivers, in optimal WUA, are caused by differences in channel size.

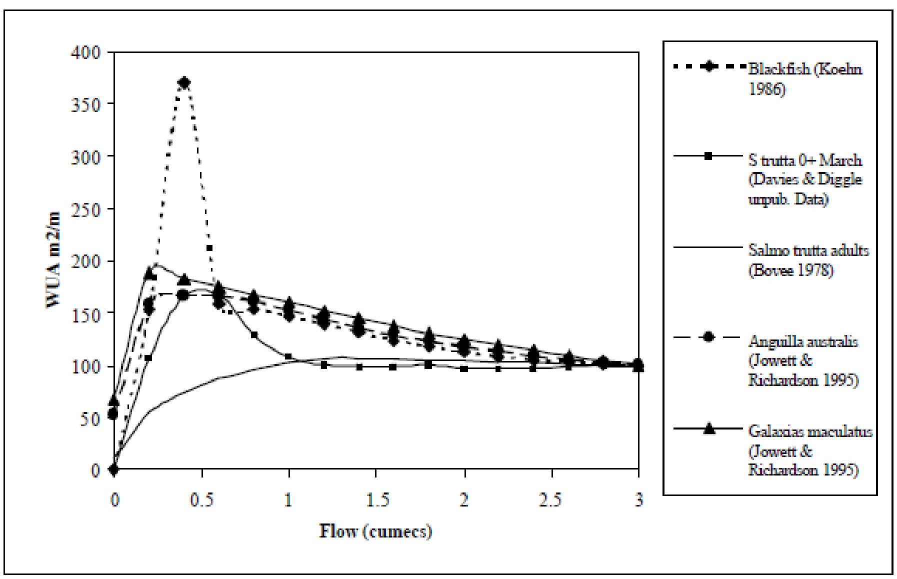

Figure 5.1: The WUA calculated for adult River Blackfish (Gadopsis marmoratus), adult Trout (Salmo trutta), late 0+ Trout (Salmo trutta), adult Shortfinned eel (Anguilla australis) and adult Jollytail (Galaxias maculatus) in the Little Forest River in Tasmania (Nelson, 2000).

The research presented here could be more reliable if there were more calibration data available. Four measurements of the flow velocities and the flow were made over the length of the study area. Figure 4.4 shows that the water surface elevations violates the continuity of flow assumption at discharges higher than 3 m^3/s. This would be more accurate if there were calibration data for every cross section. However, this was not possible because of the available time. A larger study area also improves the representativeness of a research, but here the data was complicated to collect, and so this research considers a small study area.

The HSC's were only available for the adult River Blackfish and for the other life stages the HSCs of the Two-Spined Blackfish were used. The two fish species belong to the same family and have a lot in common (Appendix D: Habitat Suitability Criteria), but the research would be more reliable if HSCs of the immature and juvenile River Blackfish were used. Considering the available time, it was not possible to the snorkelling survey by ourselves.

For further research, it would be valuable to perform a physical habitat simulation for any species of special conservation significance. For example, the Australian grayling *(Prototroctes maraena)*, which is a native fish species living in the reaches downstream Reach 1 of the Yarra River. The Australian grayling is listed as near threatened by the International Union for Conservation of Nature (IUCN, 2009) due to a definite decline in numbers since the early 20th century (Allen, Midgley, & Allen, 2003). One of the objectives for the Yarra River is to rehabilitate the populations of the Australian grayling (Sinclair Knight Merz and Melbourne Water, 2012). So, Melbourne Water should consider doing a PHABSIM analysis aimed at the Australian Grayling. To provide environmental flows that can stimulate breeding and recruitment of this species.

6 Conclusion

This research examined, whether the current minimum summer and winter flow of Reach 1 of the Yarra River adequate is for the River Black fish to complete its life cycle. This is done by simulating the physical habitat availability of the River Blackfish in Reach 1 of the Yarra River at different discharges, with the PHABSIM software.

The results showed an optimal physical habitat availability for the adult River Blackfish at a discharge of 0.126 (10 Ml/day) and an optimal physical habitat availability for the immature and juvenile River Blackfish at a discharge of 0.05 Ml/day (4.3 Ml/day). This means that, the current minimum summer and winter flow (10Ml/day), determined by Melbourne Water, is adequate for the adult River Blackfish to complete its life cycle in Reach 1 of the Yarra River. However, physical habitat availability could be improved for the immature and juvenile River Blackfish, by releasing a lower flow during the breeding season (October-January).

It is important to note that PHABSIM is only part of the IFIM methodology. Other aspects of the river environment that change with the flow and have an impact on habitat suitability (e.g. water temperature, chemical water quality, sediment transport, bed shear stress, predation, competition, food availability and fishing mortality) are not covered by PHABSIM analysis. Also, the results of the weighted usable area versus discharge (Figure 4.8) only applies on Reach 1 of the Yarra River. These results cannot be used for environmental flow assessments of other rivers. This is because the weighted usable area depends on the topographic and physical river characteristics.

The details provided by the results and the greater understanding of the results, suggest that Melbourne Water should consider doing PHABSIM modelling for species of special conservation significance, like the Australian Grayling *(Prototroctes maraena).*

7 Acknowledgements

This research project was carried out within the Environmental Hydrology and Water Resources group in the Department of Infrastructure Engineering, University of Melbourne. It was part of a bachelor thesis for the study Civil Engineering at the University of Twente in Enschede.

Firstly, I want to thank my supervisors at the University of Melbourne. I want to thank Dr. Angus Webb for his time, support and feedback during the field trips and the course of the research project. I want to thank Adrian I. Cervantes-Servin, for his support and help during the preparation of the field trips, the field trips and the Physical Habitat Simulation. Thanks also to Elise King for the hard work during the field trips.

Secondly, I also want to thank my supervisor from the University of Twente. Thanks to Dr. Marcela Brugnach for her support and feedback during the course of the research project.

I also want to thank Dr. Martijn Booij for helping me find a research topic and providing the first contact with Dr. Angus Webb, and Ellen van Oosterzee for her help during the application of the visa and the Twente Mobility Fund.

Finally, I want to thank Cheryl Edwards from Melbourne Water for providing information about the environmental flow releases in the Yarra River and Mark Lintermans for providing information about the habitat behaviour of the eggs and larvae Blackfish.

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Appendix A: Terminology

Environmental flow	Releases of water, periods of drying, or river flows allocated for the maintenance of aquatic and riparian ecosystem, measured in megalitres per day (Ml/d). (Sinclair Knight Merz and Melbourne Water, 2012)
Habitat	Habitat is the locality or external environmental in which an organism lives. Aquatic habitat can be defined as the local physical, chemical and biological features that provide a suitable environment for instream biodata. Habitat is a major determinant of aquatic community potential as it provides refuge, feeding and breeding areas for animals and plants. (Sinclair Knight Merz and Melbourne Water, 2005)
IFIM	IFIM stands for Instream Flow Incremental Methodology. IFIM is an analytical framework for addressing stream flow management issues. IFIM provides a problem solving outline for water resource issues in streams and rivers. IFIM and PHABSIM were developed as aids to instream flow decision making. The structure addresses the decision making and environment as well as the techniques for quantifying incremental differences in instream habitat that result from proposed alternative instream flow regimes (Midcontinent Edological Science Center, 2001).
MANSQ	MANSQ is one of the options in the hydraulic simulation. The MANSQ program utilizes Manning's equation to calculate water surface elevations on a cross section by cross section basis and therefore treats each cross section as independent (Midcontinent Edological Science Center, 2001).
PHABSIM	Physical Habitat Simulation (PHABSIM) is a collection of several sub-models that are developed by the U.S. Fish and wildlife Service. The development of PHABSIM started in the 1970's. The programme has been updated several times since then, and the current version was released in year 2000. The hydraulic modelling is 1-demensional and there is a choice of three sub-models to simulate water surface elevation. When water surface elevation has been simulated, the velocity can be simulated. When the hydraulic part of the modelling is concluded, the size and quality of habitat is calculated using habitat suitability criteria (Pehrson, 2007).
Physical habitat	Physical habitat is the living space of instream biodata; it is combination of spatially and temporally dynamic determined by the structural features of the channel and the hydrological regime (Maddoch, 1999).
STGQ	STGQ is one of the approaches in hydraulic simulation. The STGQ hydraulic simulation model predicts water surface elevation as a function of discharge. Given stage-discharge data, STGQ will automatically conduct the log-linear regression on the calibration data sets and determine the water surface elevations for all flows (Midcontinent Edological Science Center, 2001).
Water Surface Elevation	Water Surface Elevation (WSL), also called water surface level, is the height of the water surface at a cross section.
Weighted Useable Area	Weighted Useable Area (WUA) is the most common output from PHABSIM. This habitat measure is a combination of physical microhabitat quantity and quality. WUA is expressed in units of microhabitat area per unitized distance along a stream (e.g., m^2 per 1000m). (Midcontinent Edological Science Center, 2001)
WSP	WSP stands for the Water Surface Prole model and is one of the method options in the hydraulic simulation. WSP uses the step backwater method to obtain a 1-dimensional representation of the flow (Midcontinent Edological Science Center, 2001).

Appendix B: Cross section Characterization

To determine the environmental flow, PHABSIM needs some characteristics of the river. These characteristics are given to the simulation program per cross section. For every cross section, the value of Manning's n and the channel index is determined.

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Table B. 1: The Manning's n Number. (Chow, 1959)

The total station was moved nine times during the measurement of the topographic survey. The measurements began upstream within the study area and ended at the downstream end. In PHABSIM the first cross section needs to be the cross section downstream the study area. For this reason, is the first cross sections measured, called cross section 22, the second cross section measured called 21 etc.

B.1 Station 1, Cross Section 21 and 22.

Figure B. 1: Station 1, Cross Sections 21 and 22.

Cross section 21:

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, Straight, no deep pools	Normal	0.030	Organic debris <50% density	2

Cross section 22:

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, Straight, no deep pools	Normal	0.030	Organic debris <50% density	2

B.2 Station 2, Cross section 20

Figure B. 2: Station 2, Cross Sections 20.

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
clean, straight, more stones and weeds	Normal	0.035	Organic debris >50% density	3

B.3 Station 2, Cross Section 19

Figure B. 3: Station 2, Cross Section 19.

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
clean, straight, more stones and weeds	Normal	0.035	Organic debris >50% density	3

B.4 Station 3, Cross Section 18

Figure B. 4: Station 3, Cross Section 18.

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, straight, no rifts or deep pools	Normal	0.030	Organic debris >50% density	3

B.5 Station 3, Cross Section 16 and 17

Figure B. 5: Station 3, Cross Section 16 and 17.

Cross section 16:

Type of Channel and Description	Minimum/Normal /Maximum	Manning's n value	Instream cover habitat	Channel Index
Winding, weeds and stones	Maximum	0.050	Organic debris <50% density	2

Cross section 17:

Type of Channel and Description	Minimum/Normal /Maximum	Manning's n value	Instream cover habitat	Channel Index
Clean, straight, no rifts or deep pools	Normal	0.030	Organic debris >50% density	3

B.6 Station 4, Cross Section 15

Figure B. 6: Station 4, Cross Section 15 (Google maps, 2016)

Type of Channel and Description	Minimum/Normal /Maximum	Manning's n value	Instream cover habitat	Channel Index
Straight, full stage, no rifts of deep pools but more stones and weeds	Maximum	0.040	Organic debris <50% density	2

B.7 Station 5, Cross Section 14

Figure B. 7: Station 5, Cross section 14

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean straight, no deep pools	Normal	0.030	Organic debris <50% density	2

B.8 Station 5, Cross Section 13

Figure B. 8:Station 5, Cross Section 13 (Google.maps,2016).

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Straight, no rifts or deep pools	Normal	0.030	Organic debris >50% density	3

B.9 Station 6, Cross Section 12

Figure B. 9: Station 6, Cross section 12

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, some pools	Normal	0.040	Organic debris >50% density	3

B.10 Station 6, Cross Section 11

Figure B. 10: Station 6, Cross Section 11 (Google maps, 2016)

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, some pools	Normal	0.040	Organic debris >50% density	3

B.11 Station 6, Cross Section 10

Figure B. 11:Station 6, Cross section 10.

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Straight, clean, no rifts or deep pools	Normal	0.030	Organic debris >50% density	3

B.12 Station 7, Cross Section 9

Figure B. 12: Station 7, Cross section 9

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, winding, with more stones	Maximum	0.060	Organic debris <50% density	2

B.13 Station 7, Cross Section 8

Figure B. 13: Station 7, Cross section 8

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning’s n value**	**Instream cover habitat**	**Channel Index**
Clean, winding, some weeds and stones	Normal	0.045	Organic debris <50% density	2

B.14 Station 8, Cross Section 6 and 7

Figure B. 14: Station 8, Cross section 6 and 7.

Cross section 6:

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, winding, with some weed and stones	Normal	0.045	Organic debris <50% density	2

Cross section 7:

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, winding, with some weed and stones	Normal	0.045	Organic debris <50% density	2

B.15 Station 8, Cross Section 4 and 5

Figure B. 15: Station 8, Cross section 4 and 5

Cross Section 4:

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, straight, no rifts or deep pools	Normal	0.030	Organic debris >50% density	3

Cross Section 5:

Type of Channel and Description	**Minimum/Normal /Maximum**	**Manning's n value**	**Instream cover habitat**	**Channel Index**
Clean, straight, no rifts or deep pools	Normal	0.030	Organic debris >50% density	3

B.16 Station 9, Cross Section 1, 2 and 3

Figure B. 16: Station 9, Cross Section 1, 2 and 3.

Cross Section 1:

Type of Channel and Description	Minimum/Normal /Maximum	Manning's n value	Instream cover habitat	Channel Index
Clean, straight, no rifts or deep pools	Normal	0.030	Organic debris <50% density	2

Cross Section 2:

Type of Channel and Description	Minimum/Normal /Maximum	Manning's n value	Instream cover habitat	Channel Index
Clean, straight, no rifts or deep pools	Normal	0.030	Organic debris <50% density	2

Cross Section 3:

Type of Channel and Description	Minimum/Normal /Maximum	Manning's n value	Instream cover habitat	Channel Index
Clean, straight, no rifts or deep pools	Normal	0.030	Organic debris <50% density	2

Appendix C: Devices

C.1 Total Station

Brand	Sokkia
Model	SET5X

Figure C. 1: A picture of the Total Station used in this research project.

Figure C. 2: A picture of the prism used in this research project.

C.2 Velocity meter

Brand	HYQUEST Solutions
Current Meter Model	OSS-PC1
Fan No.	1
Diameter	50mm
Type of support	9mm

Figure C. 3: Velocity meter (HYQUEST SOLUTIONS, 2015).

Figure C. 4: A picture of a flow velocity measurement being taken. The velocity meter is connected to the metal pipe, which is also show in the picture. The metal pipe is also used to determine the depth of the river.

Appendix D: Habitat Suitability Criteria

Figure D. 1 and Figure D. 2 show the Habitat Suitability Criteria for the Adult Two-spined Blackfish and the Adult River Blackfish. Both graphs show many similarities, but the Two-spined Blackfish prefers deeper pools and higher velocities.

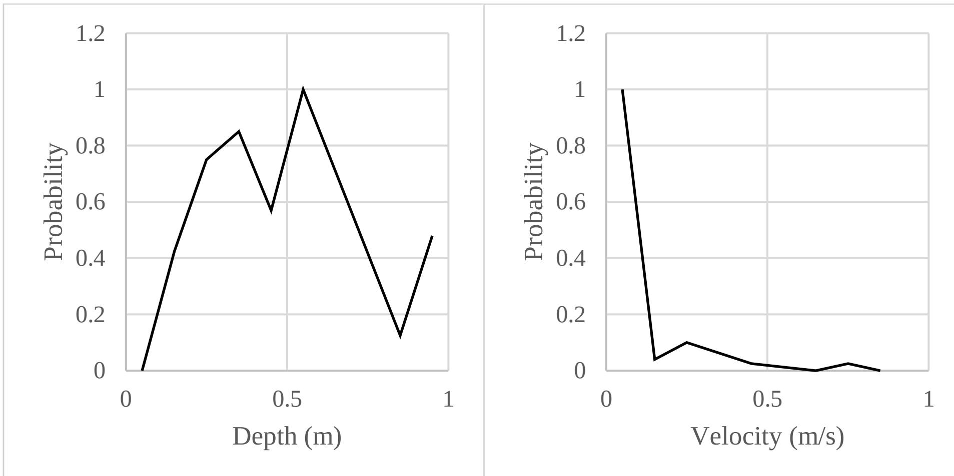

Figure D. 1: The Habitat Suitability Criteria for the Adult Two-spined Blackfish (Gadopsis bispinosus) (Maddock, Thoms, Jonson, Dyer, & Lintermans, 2004).

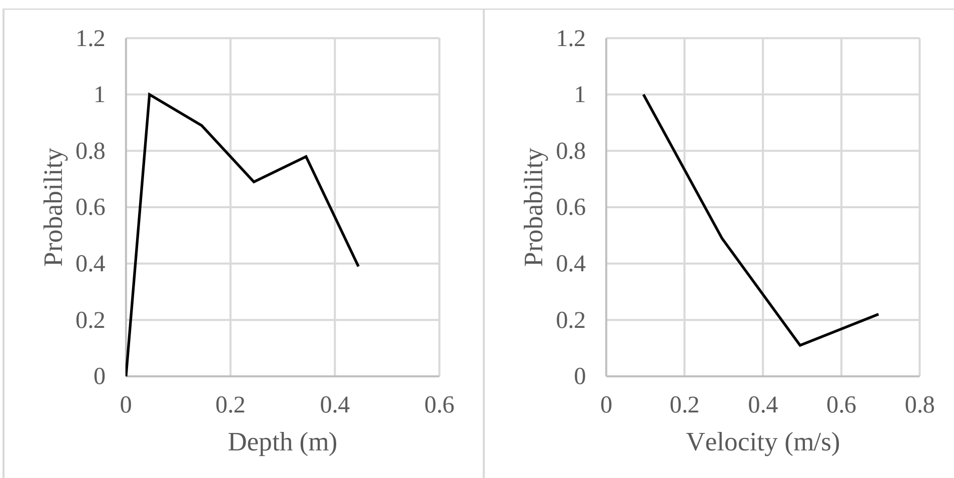

Figure D. 2: The Habitat Suitability Criteria for the River Blackfish (Gadopsis marmoratus) (Koehn, 1986).

Appendix E: Water Surface Elevations and Flow Velocities

The water surface elevations and the related flow velocities for the different discharges: 0.126 m^3/s, 0.187 m^3/s, 0.247 m^3/s, 0.625 m^3/s 0.694 m^3/s, 1.0 m^3/s, 1.157 m^3/s, 1.5 m^3/s, 2.0 m^3/s, 2.5 m^3/s, 3 m^3/s and 3.472 m^3/s.

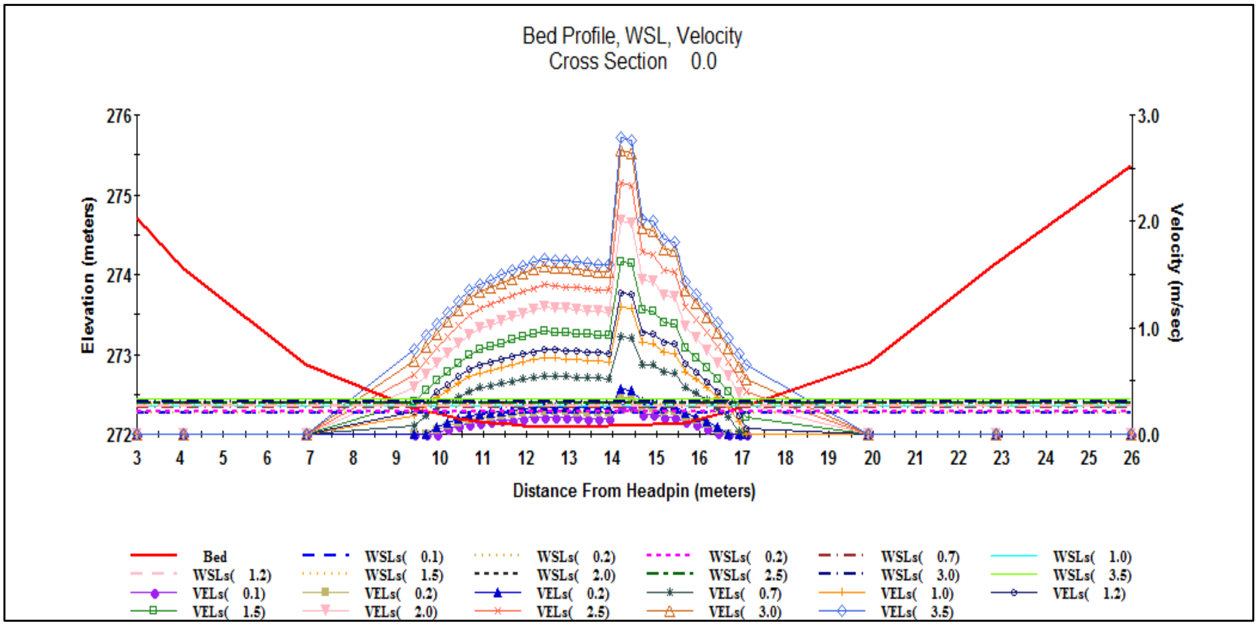

Figure E. 1: Water Surface Elevations and Flow Velocities of cross section 1 at different discharges.

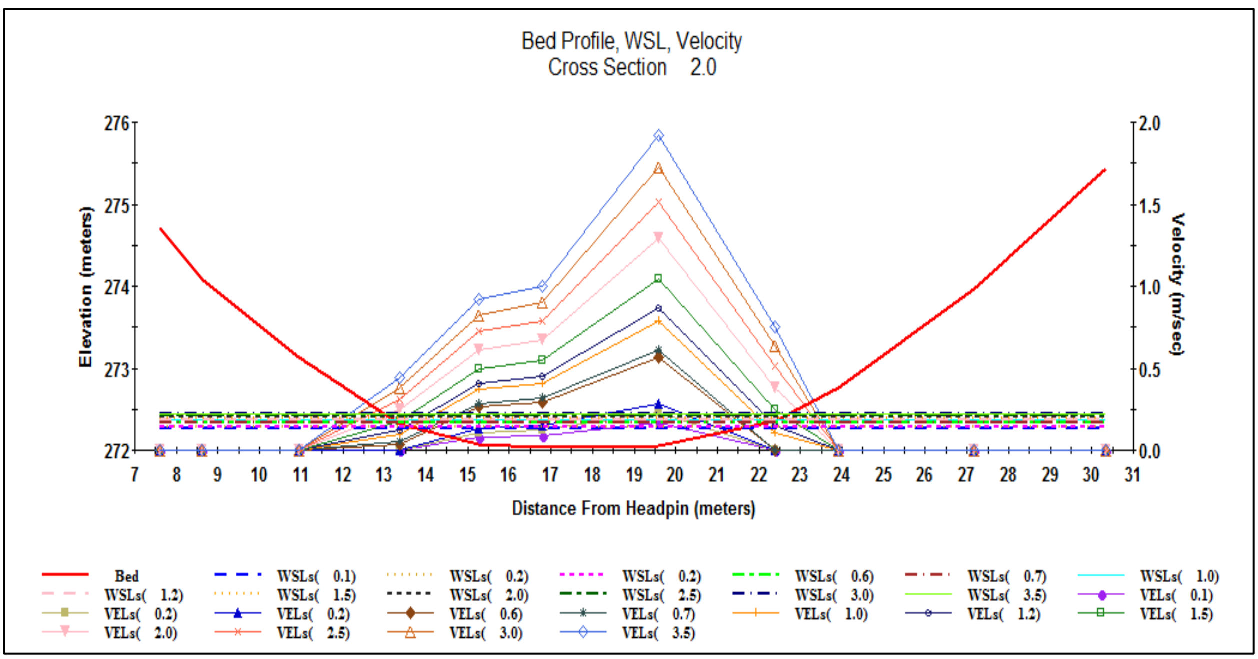

Figure E. 2: Water Surface Elevations and Flow Velocities of cross section 2 at different discharges.

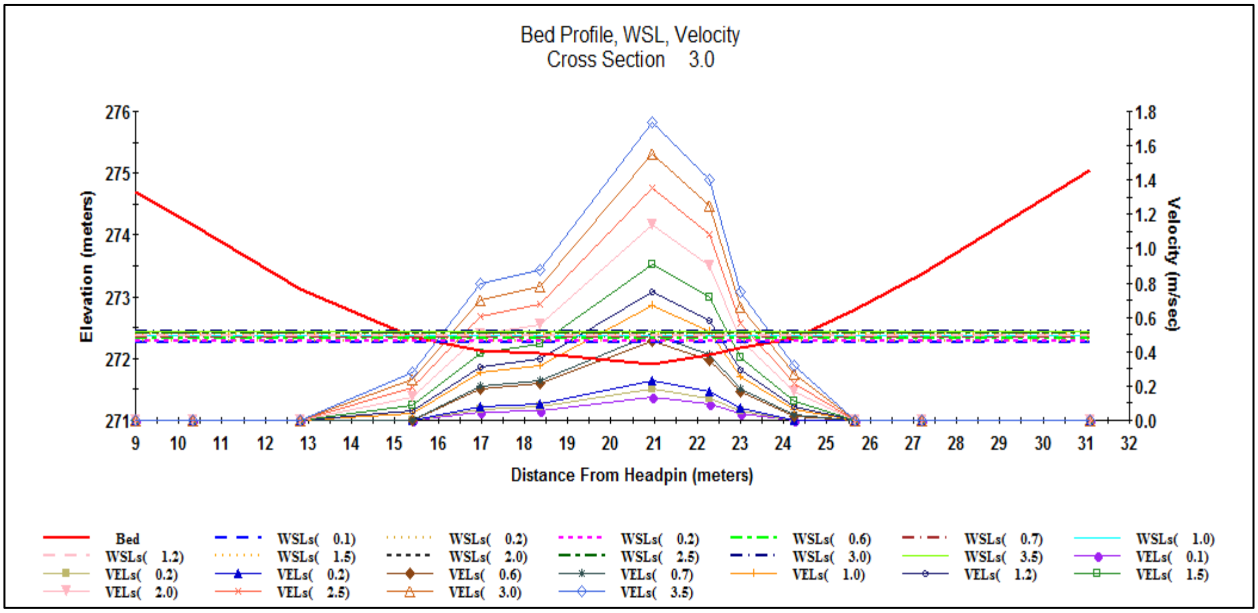

Figure E. 3: Water Surface Elevations and Flow Velocities of cross section 3 at different discharges.

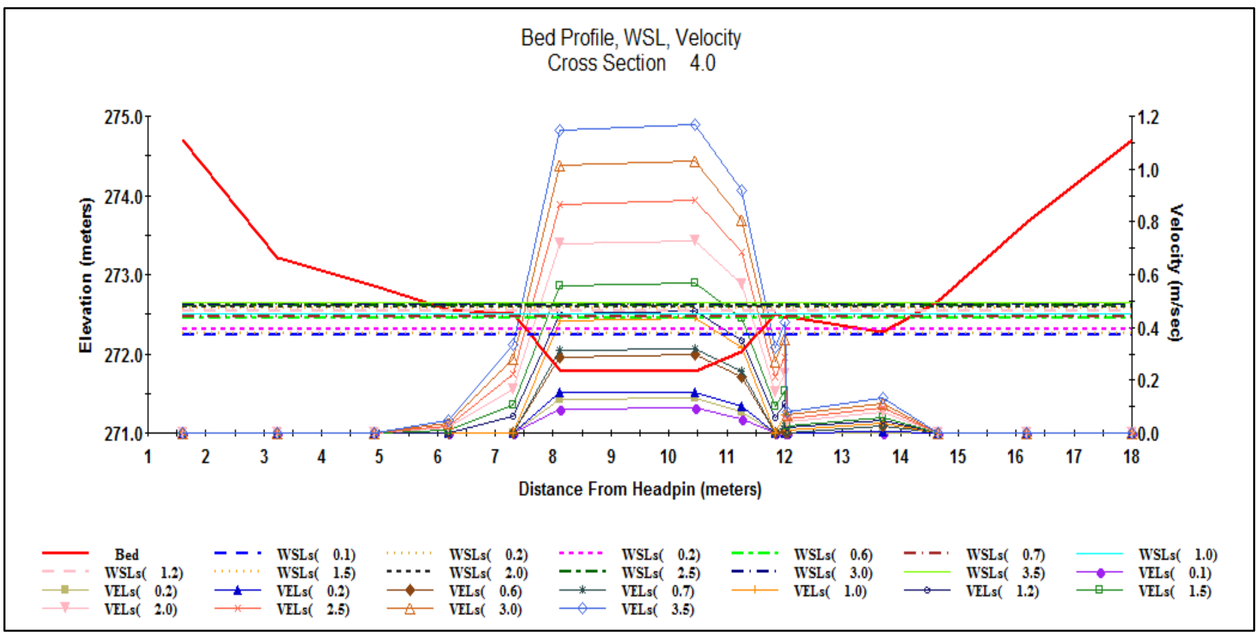

Figure E. 4: Water Surface Elevations and Flow Velocities of cross section 4 at different discharges.

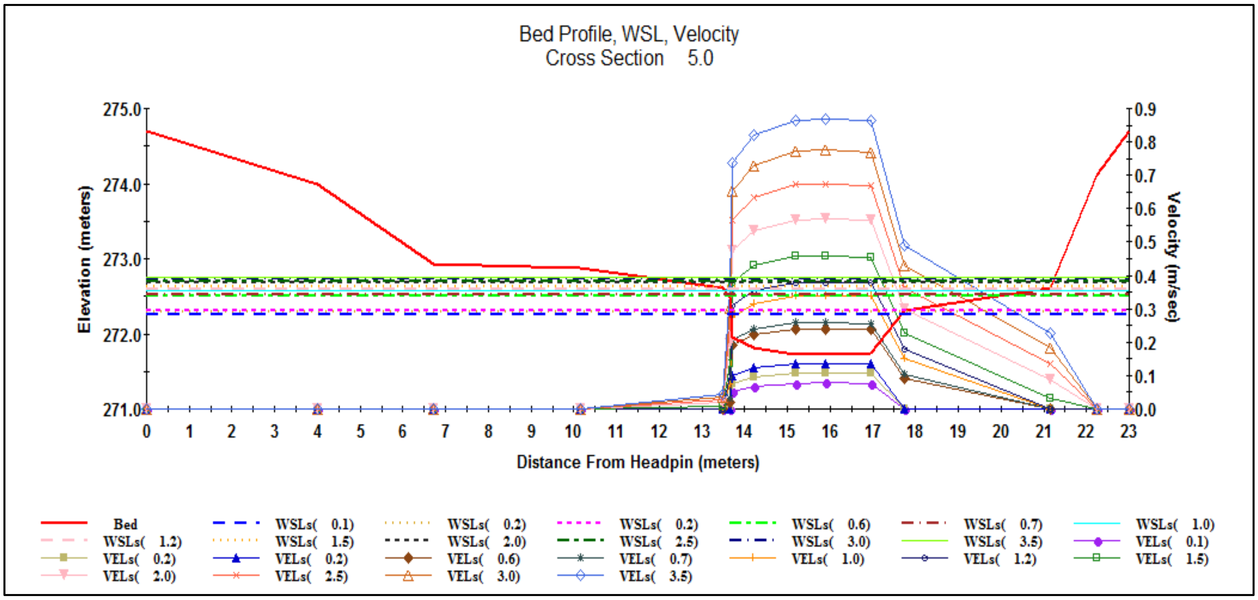

Figure E. 5: Water Surface Elevations and Flow Velocities of cross section 5 at different discharges.

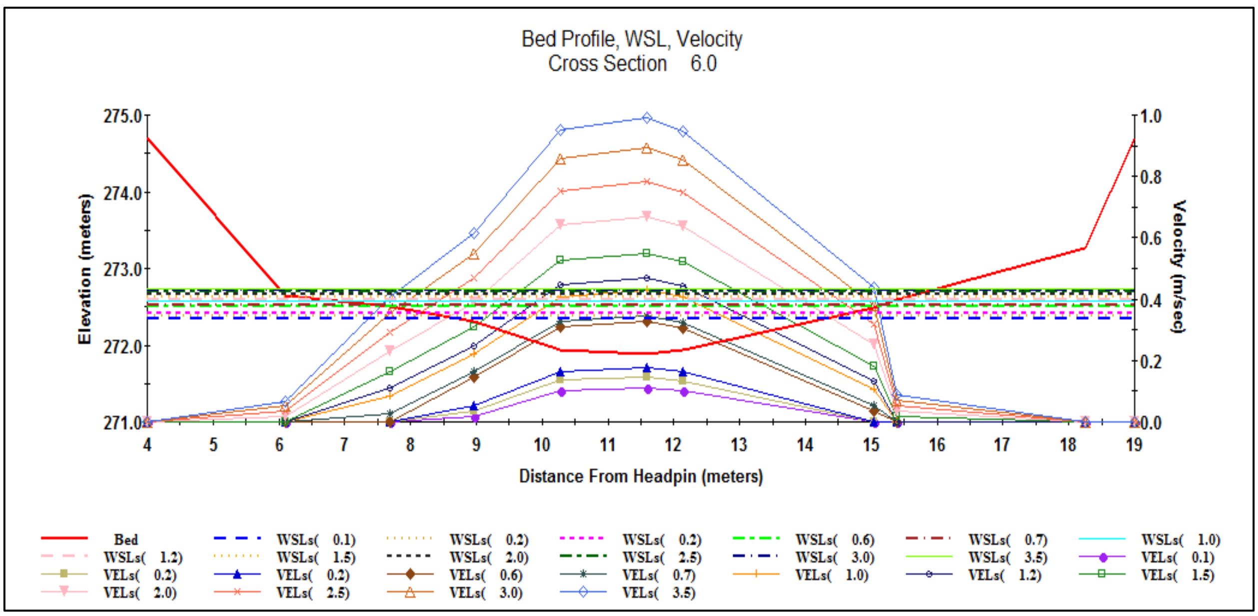

Figure E. 6:Water Surface Elevations and Flow Velocities of cross section 6 at different discharges.

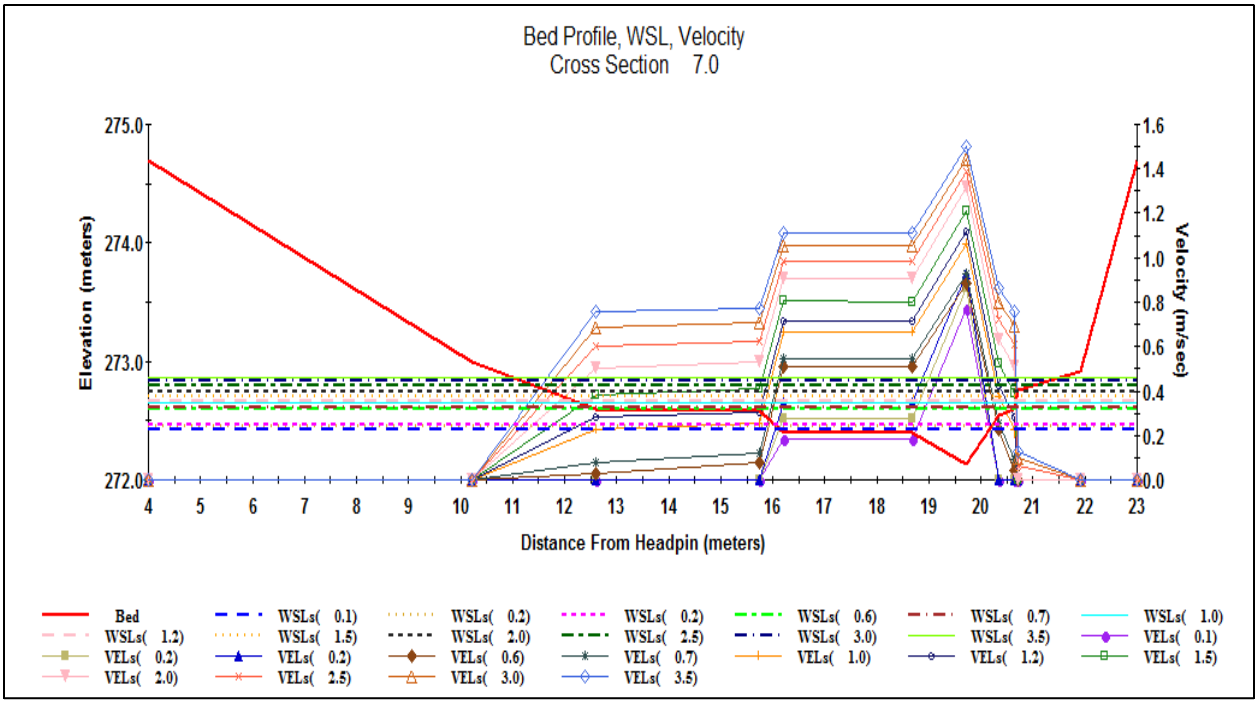

Figure E. 7: Water Surface Elevations and Flow Velocities of cross section 7 at different discharges.

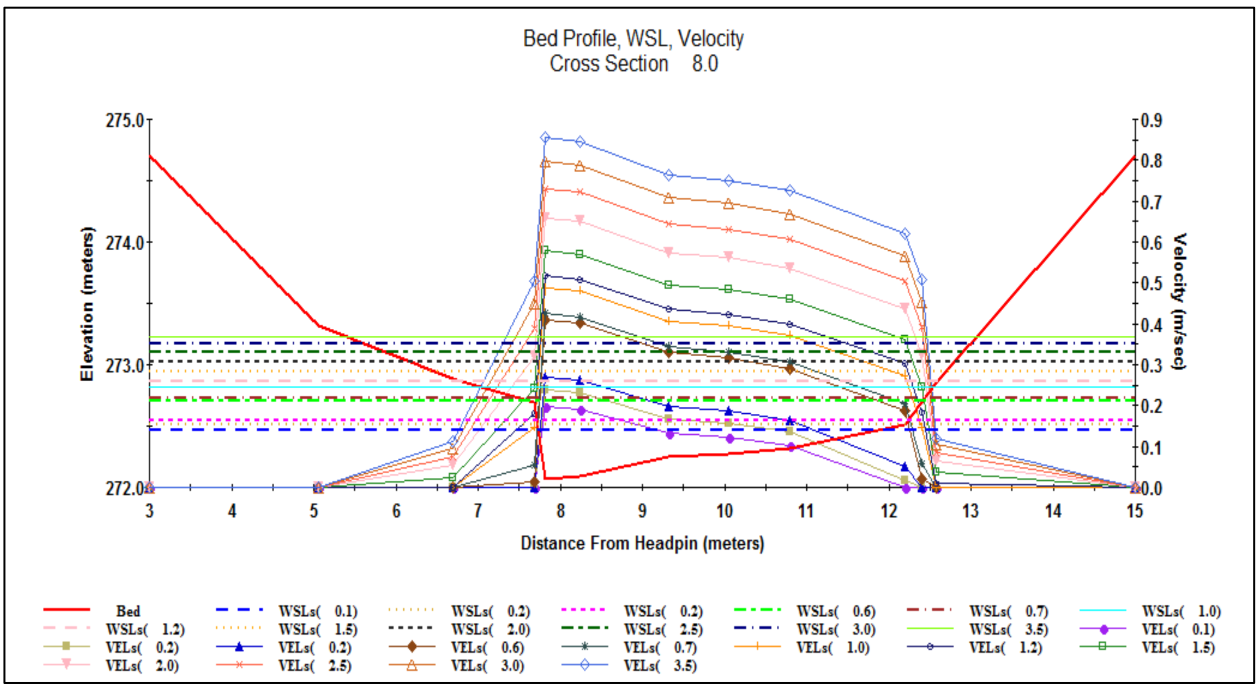

Figure E. 8: Water Surface Elevations and Flow Velocities of cross section 8 at different discharges.

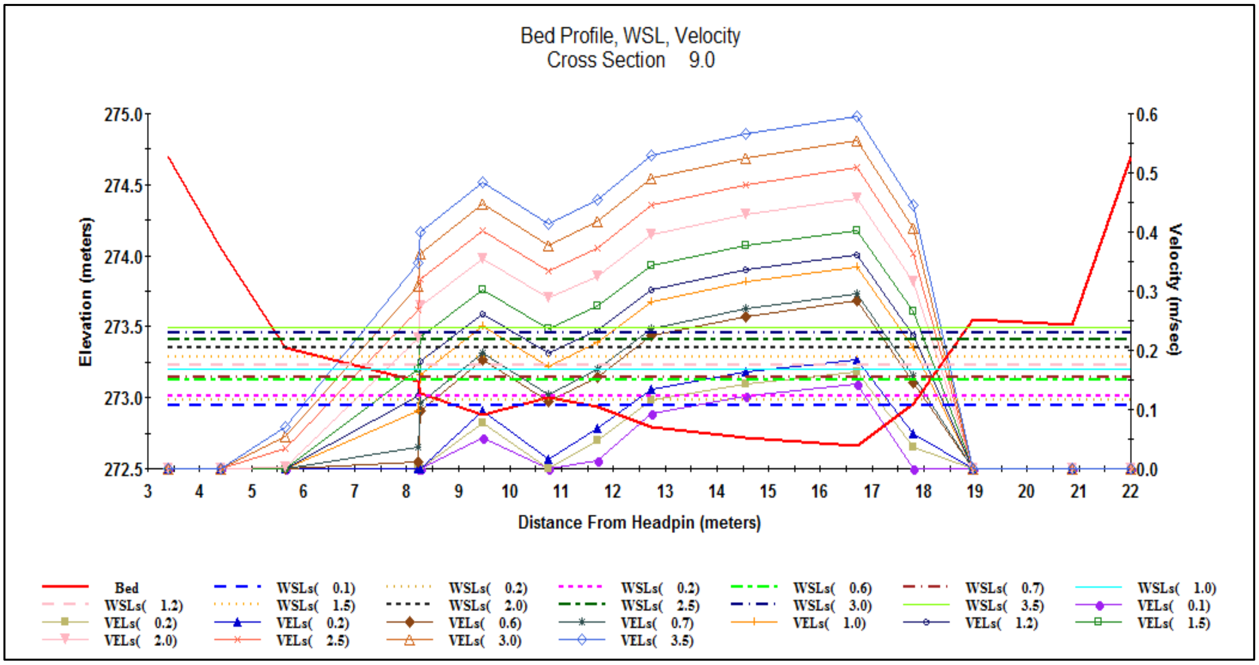

Figure E. 9: Water Surface Elevations and Flow Velocities of cross section 9 at different discharges.

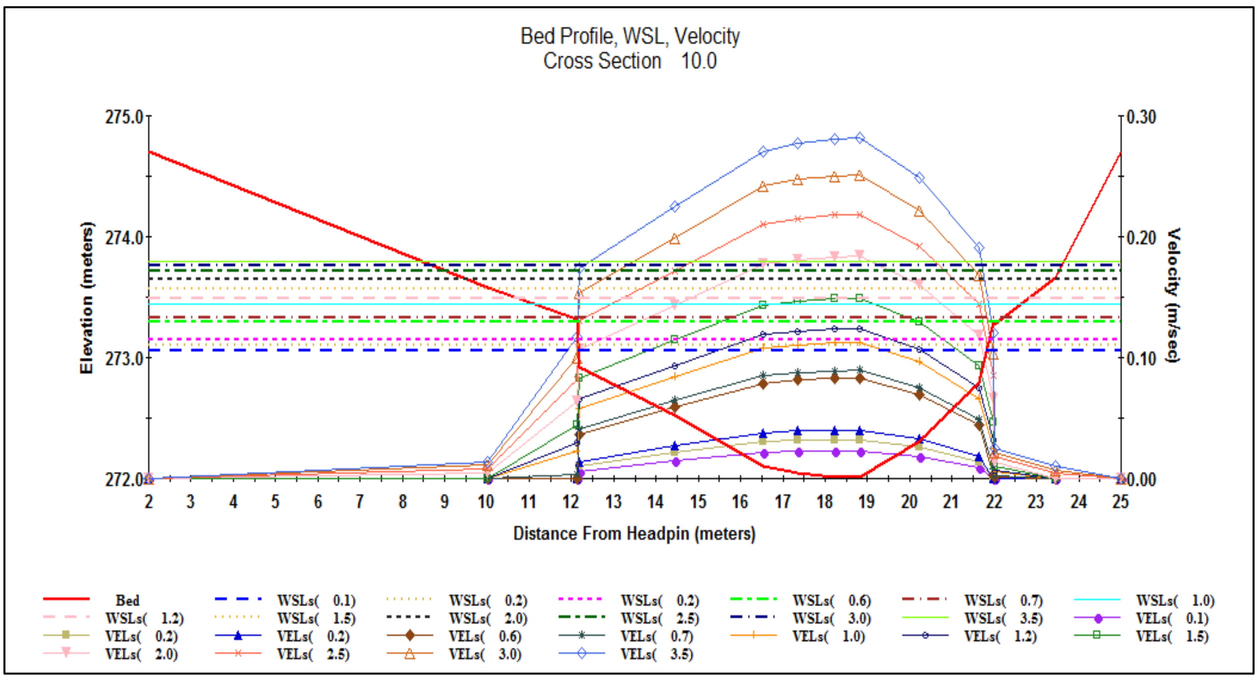

Figure E. 10:Water Surface Elevations and Flow Velocities of cross section 10 at different discharges.

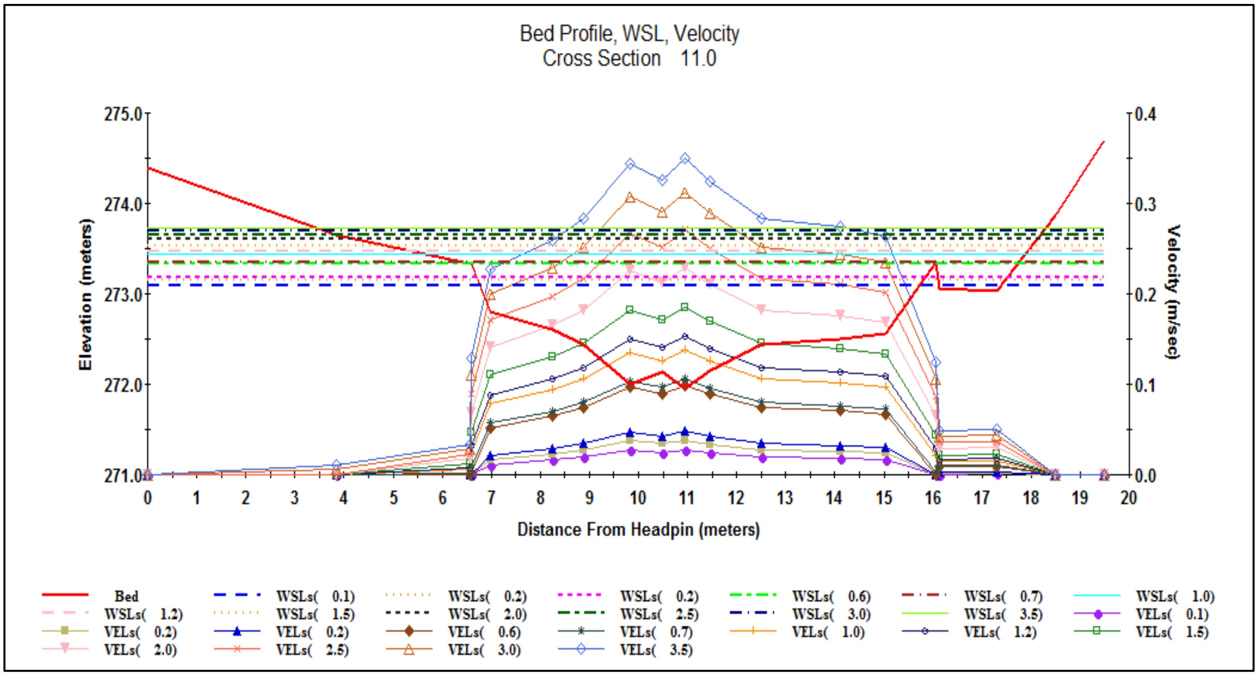

Figure E. 11: Water Surface Elevations and Flow Velocities of cross section 11 at different discharges.

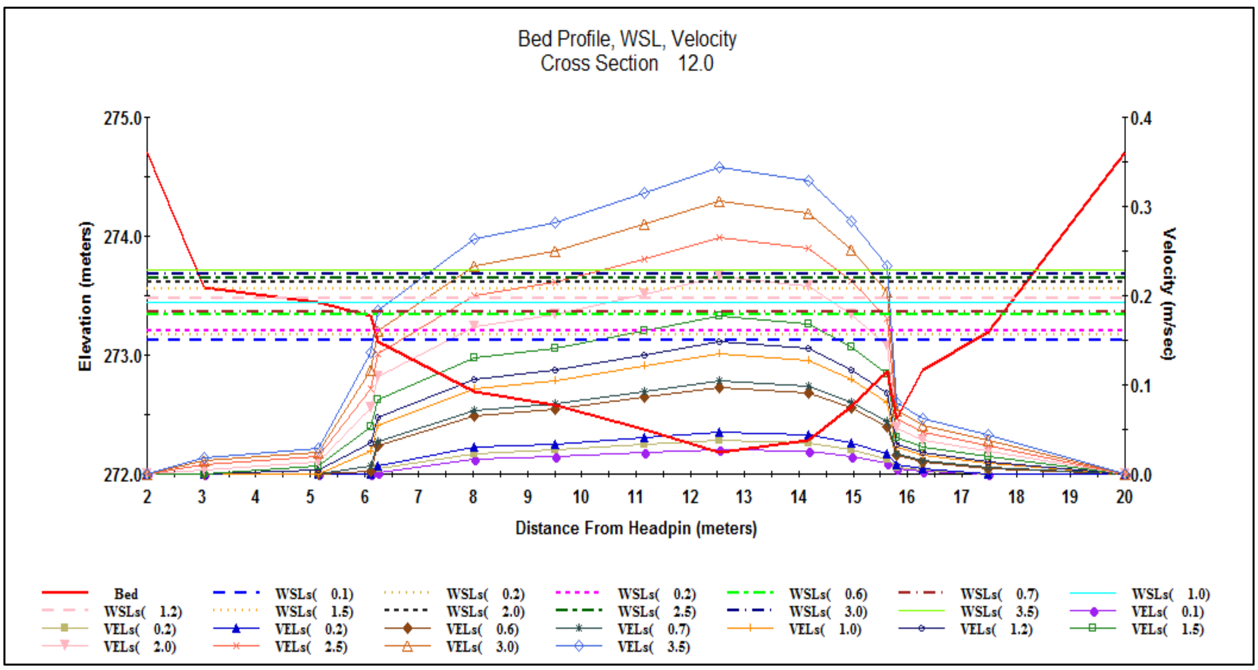

Figure E. 12: Water Surface Elevations and Flow Velocities of cross section 12 at different discharges.

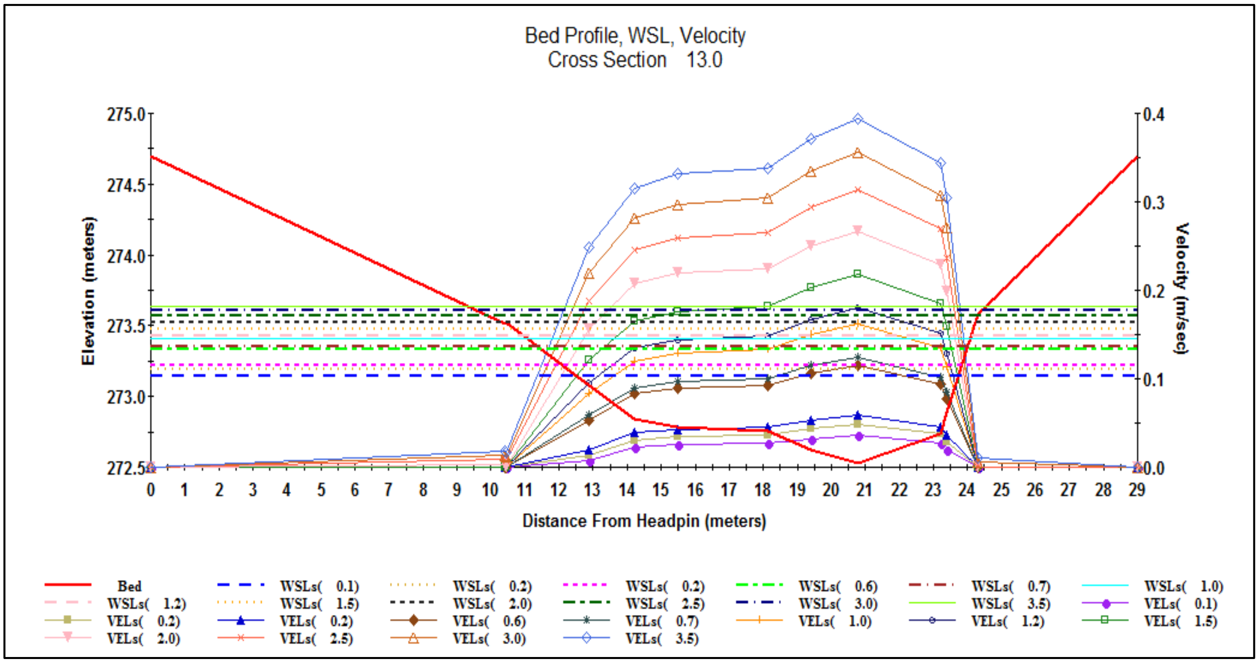

Figure E. 13: Water Surface Elevations and Flow Velocities of cross section 13 at different discharges.

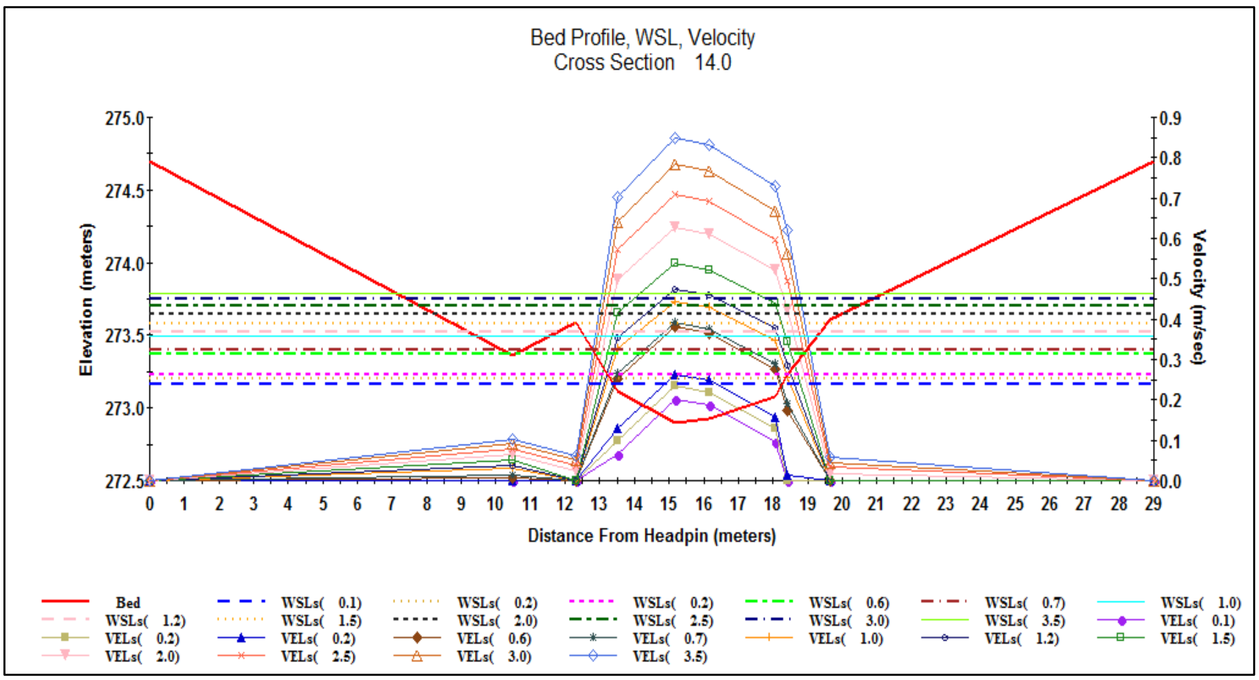

Figure E. 14: Water Surface Elevations and Flow Velocities of cross section 14 at different discharges.

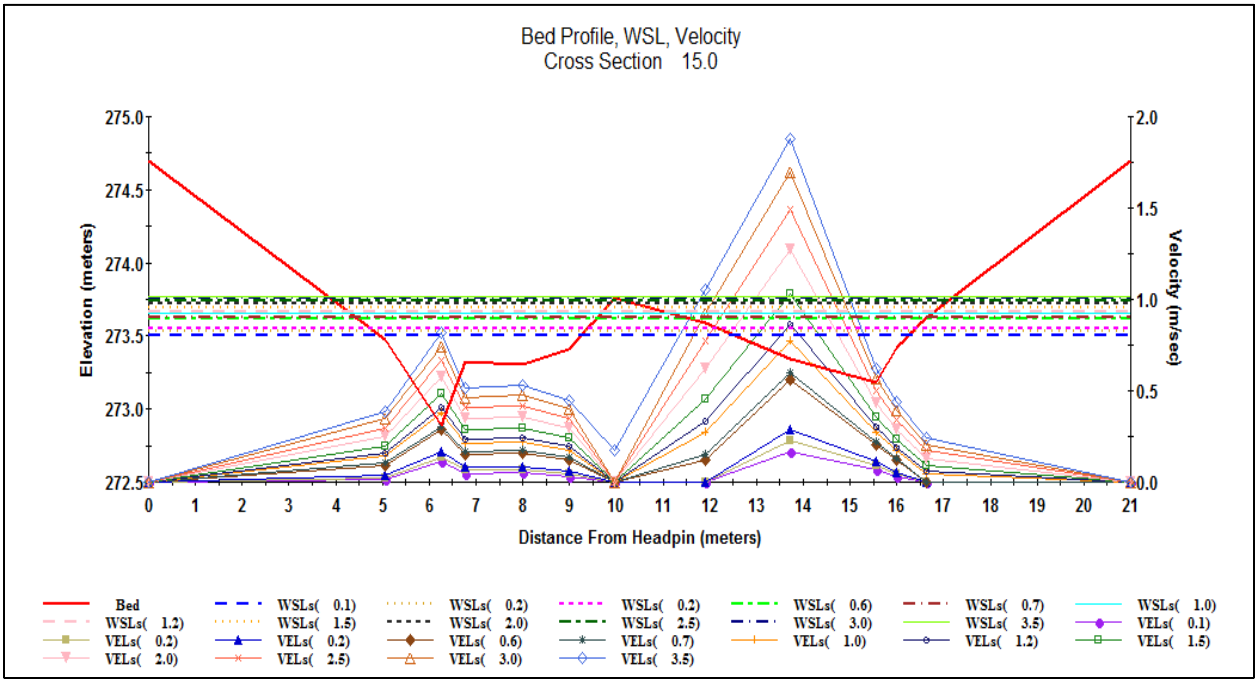

Figure E. 15: Water Surface Elevations and Flow Velocities of cross section 15 at different discharges.

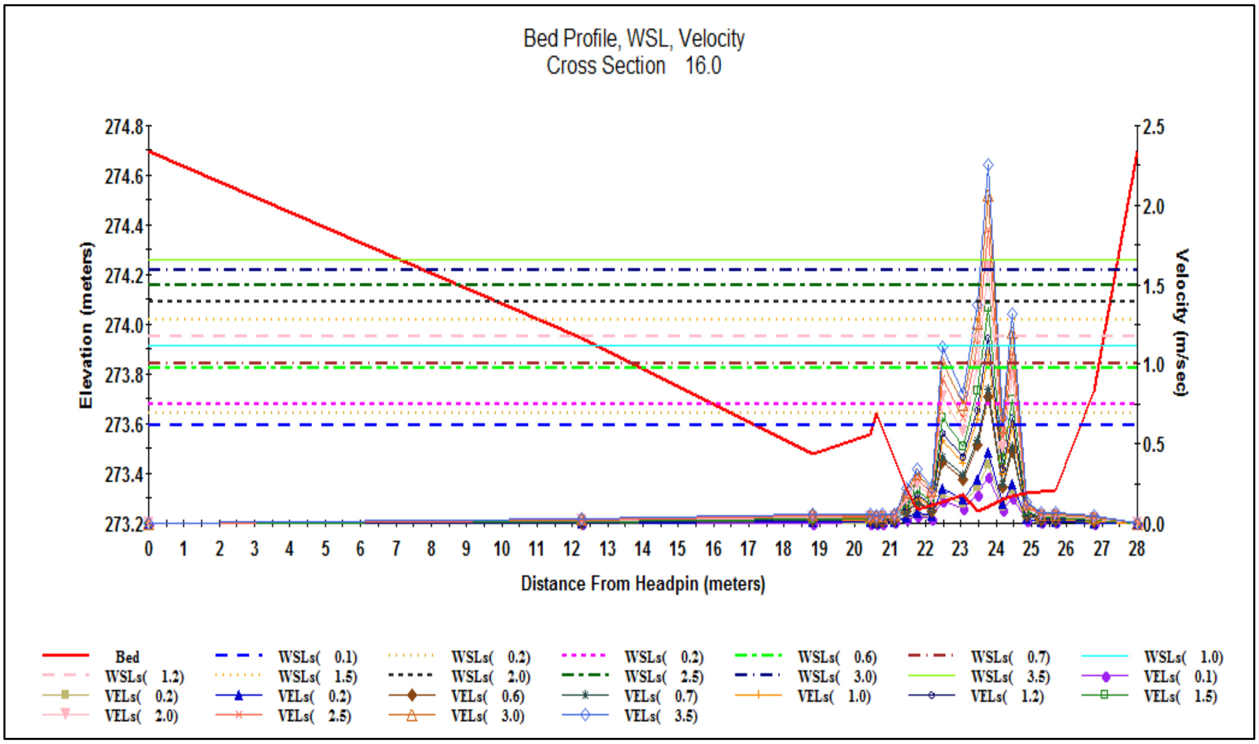

Figure E. 16: Water Surface Elevations and Flow Velocities of cross section 16 at different discharges.

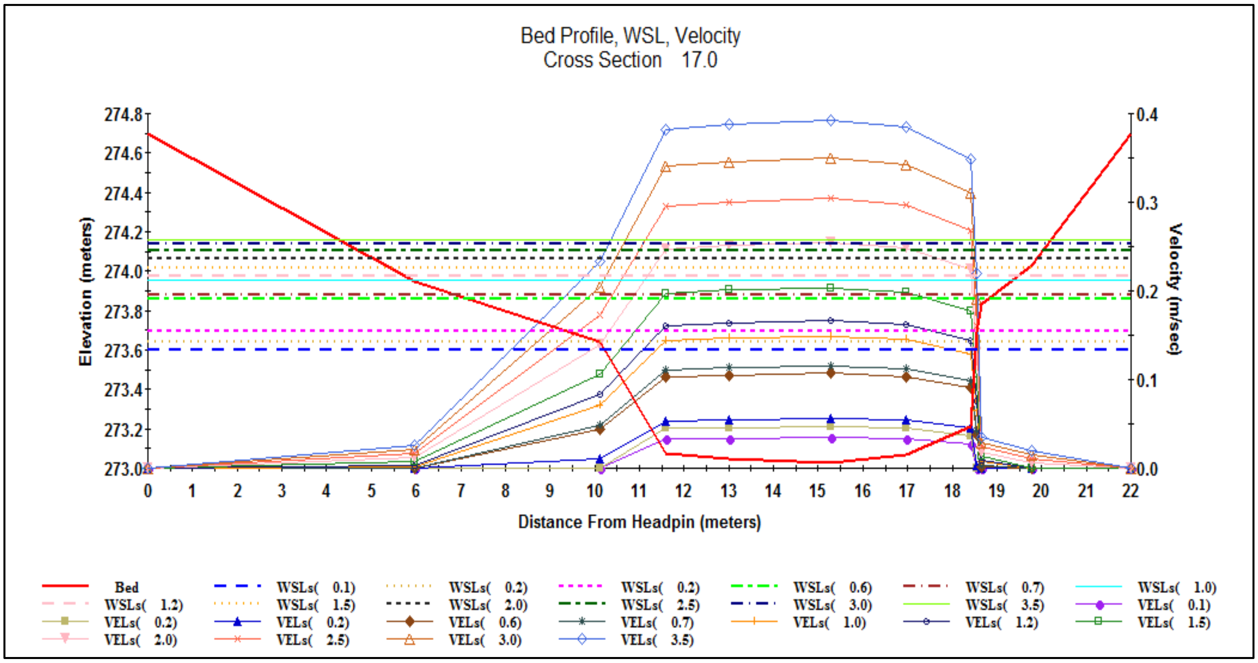

Figure E. 17: Water Surface Elevations and Flow Velocities of cross section 17 at different discharges.

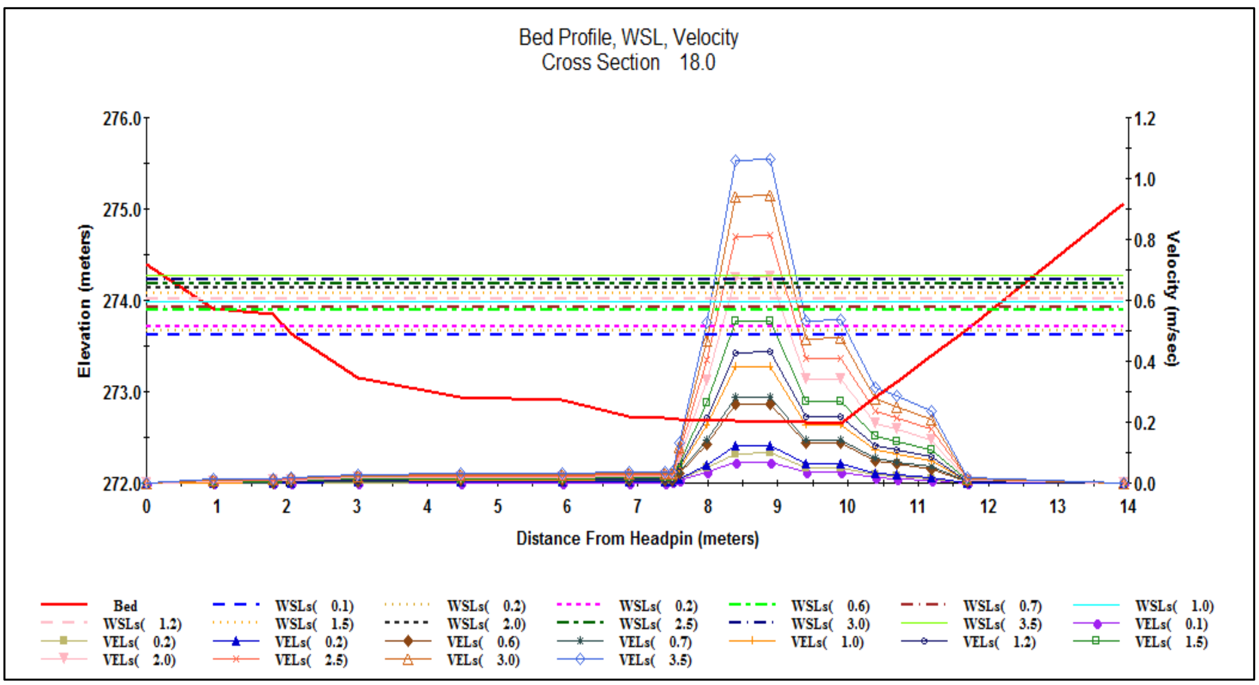

Figure E. 18: Water Surface Elevations and Flow Velocities of cross section 18 at different discharges.

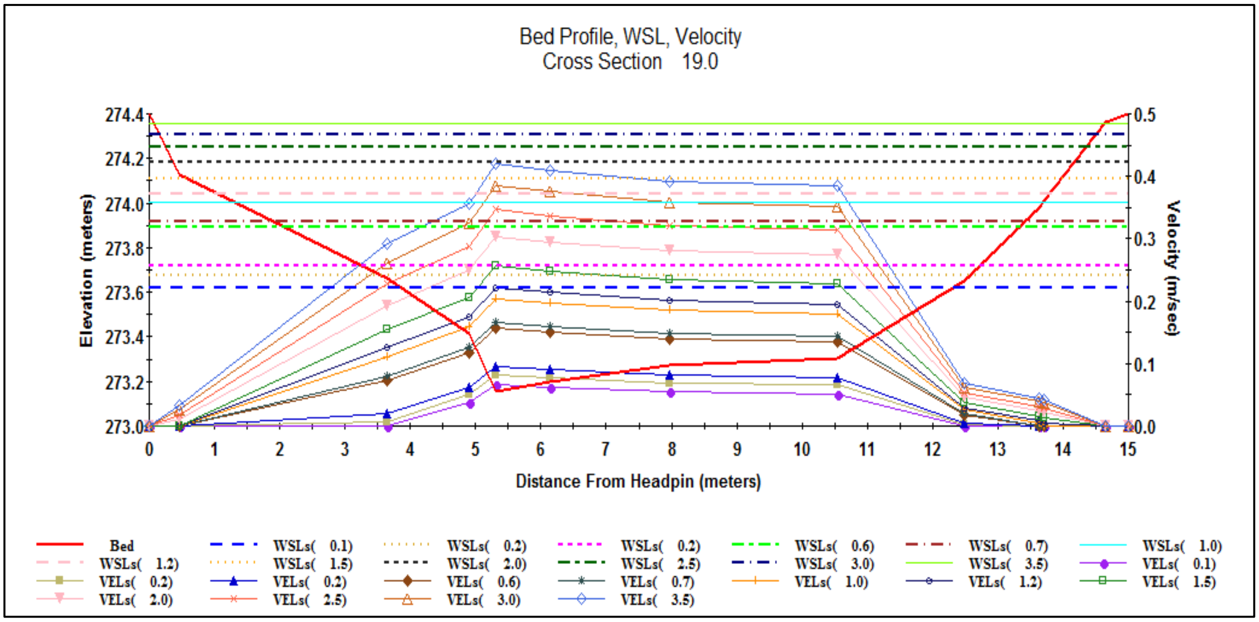

Figure E. 19: Water Surface Elevations and Flow Velocities of cross section 19 at different discharges.

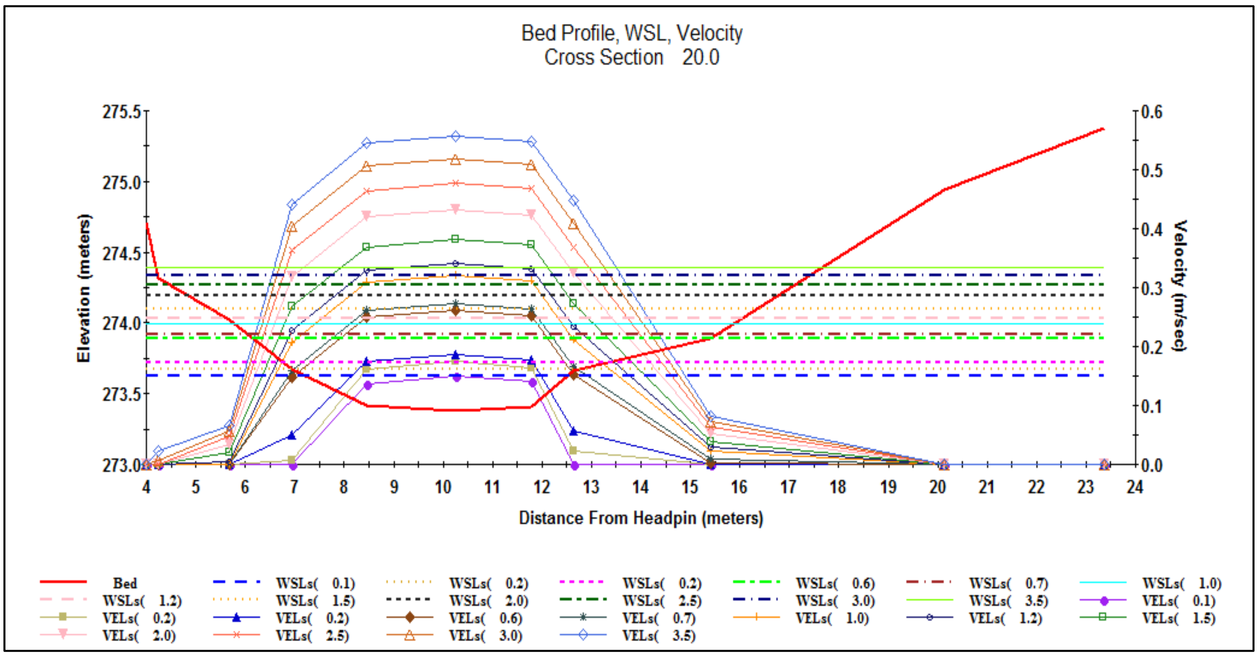

Figure E. 20: Water Surface Elevations and Flow Velocities of cross section 20 at different discharges.

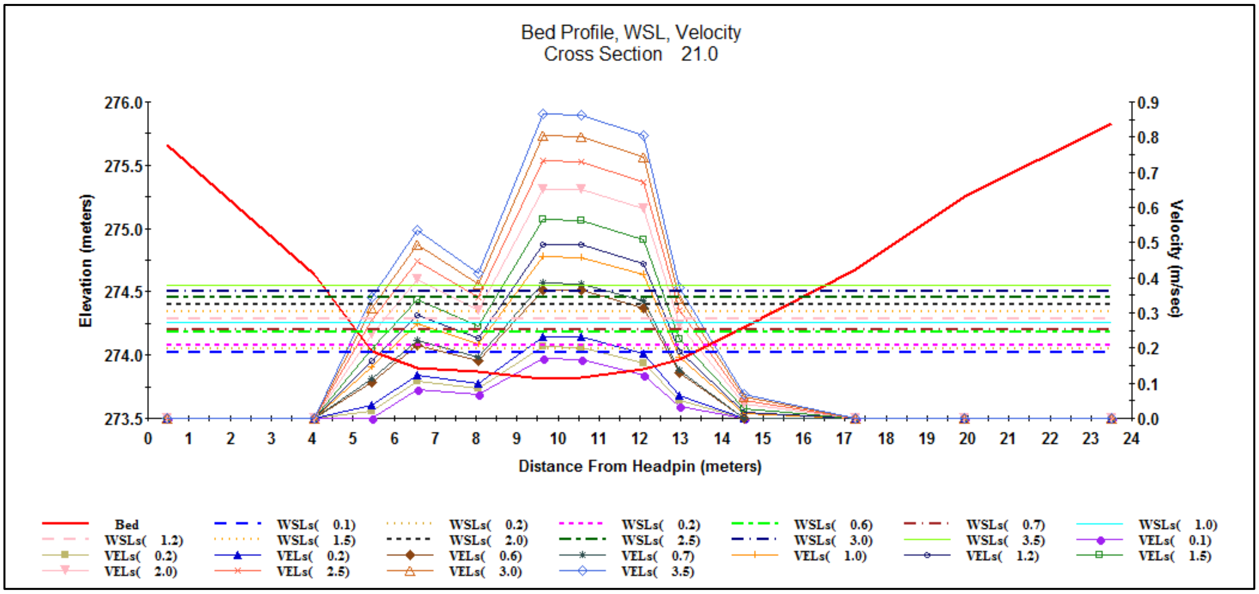

Figure E. 21: Water Surface Elevations and Flow Velocities of cross section 21 at different discharges.

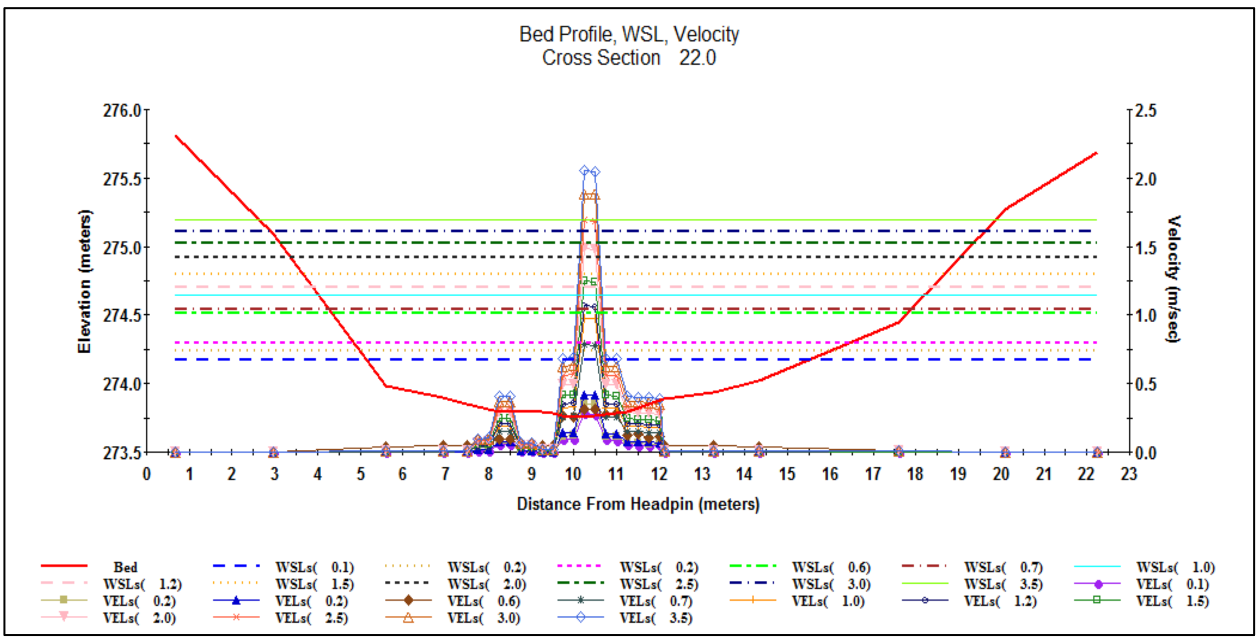

Figure E. 22: Water Surface Elevations and Flow Velocities of cross section 22 at different discharges.