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Master of Science in Civil Engineering

HYDRAULIC BASED ASSESSMENT OF ECOLOGICAL FLOWS. THE CASE STUDY OF LOWLAND TICINO AND ADDA RIVERS.

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ABSTRACT

In this thesis, we studied the effect of discharge variation caused by diversion of irrigation channels on two species of fish, marble trout and barbus barbus. We used habitat suitability index approach for two riverine parameters current velocity and water depth. The hydraulic modelling of Ticino and adda rivers were carried out using HEC-RAS 1D software, the model was calibrated comparing the observed and simulated Water Surface Levels(WSL). Water depths and channel velocities obtained from the hydraulic simulations, were used for the assessment of the Habitat suitability criteria (HSC) and weighted usable area (WUA) for the species of fish. Minimum Environmental Flows were calculated with the relationship between WUA and discharges and WUA flow Duration Curves.

KEYWORDS: HEC_RAS, Habitat Suitability criteria, Weighted Usable Area

CHAPTER 1

INTRODUCTION

Freshwater is a critical and finite resource for human development and conservation of biodiversity. The human water demand is constantly increasing(Postel 1998), placing at risk aquatic environment and human development itself. Over half of the world's accessible surface water is already pirated by humans(Postel 1998)(Postel, S.L.; Daily, G.C.; Ehrlich 2008). To fulfil their demands they are constructing different types of hydraulic structures such as dams for hydropower, or channel diversions for agricultural purposes.

It is recognized that the structure and functions of a stream ecosystem are significantly influenced by flow conditions. Impoundments, diversion weirs, interbasin water transfers, run-of-river abstraction, aquifer exploitation for the primary uses of irrigated agriculture, hydropower generation, industry, and domestic supply are all responsible for unprecedented impacts on riverine ecosystems around the world. The majority of which are caused by changes to the natural hydrological regime. A substantial body of scientific evidence has accumulated in support of the natural flow paradigm. The river's flow regime, which includes the five key components of variability, magnitude, frequency, duration, timing, and rate of change, is recognized as critical to maintaining biodiversity and ecosystem integrity(Poff and Ward 1989)(Richter et al. 1997)(Grimm, Pickett, and Redman 2000). Hydrological changes are one of many environmental issues in the world today, and their biological consequences in catchments are difficult to distinguish from those of other environmental perturbations.

Increased worldwide water demands have posed a difficulty for water management institutions. To overcome this difficulty different forms of aquatic evaluation techniques are generated to analyse the environmental sustainability of alternative water management systems(Tharme 2003). The need to predict the biological effects of water management activities and set water management goals that protect riverine biota, socially valuable goods and services associated with riverine ecosystems has prompted a new scientific discipline of "instream flow" modelling and design (Richter et al. 1997).

Previous studies have provided valuable insights into the ecological modelling and assessment of stream habitats(Schwartz 2008).The Eco hydraulic assessment (also known as hydraulic microhabitat assessment) is one type of instrument that seeks to describe river physical habitat at a spatial scale that is supposed to be consistent with the Individual aquatic species, mainly fish(Nestler et al. 2019).

Individuals of native riverine species have life history features that allow them to survive and reproduce in a wide range of environmental conditions(TOWNSEND and HILDREW 1994)(Stanford et al. 1996). A variety of environmental characteristics are known to shape habitat templates that controls the distribution of aquatic and riparian species(Society 2017). These include flow depth, velocity, temperature, substrate size distribution, oxygen content , turbidity, soil moisture/saturation and other physical and chemical conditions and biotic influences (Allan, 1995).

Freshwater fish habitat requirements, commonly described as Habitat Suitability Curves (HSCs), can provide useful information on a stream channel's physical structure and flow regime. When a river is identified in critical condition for a short length of time, minimum environmental flows are calculated for keeping it alive and protecting its ecology(Nikghalb et al. 2016). Minimum environmental flows are recognized by the relationship between WUA and discharge.

Estimates of depth and velocity, which can be produced using a computational hydraulic model, are required for WUA estimations and habitat indexing. One-dimensional river models are significantly more popular and widely used for hydraulic simulations. However, to establish the regional distribution of habitat suitability indices (SI), more comprehensive hydrological data is required(K D Bovee et al. 1998).

Habitat suitability criteria may be expressed in various type and formats. The types or category refers to the procedure used to develop the criteria

Category I: criteria are based on professional judgment with no or little empirical data.

Category II: criteria have as their own source, microhabitat data collected at location where targeted organisms are observed or captured. These are called “utilization” functions because they are based on observed location that were used by the targeted organism.

Category III: correction of these utilization function for environmental availability creates category III.

Habitat suitability criteria are not always developed from field studies there are numerous situations that can dictate the formulation of category I criteria, which are based on literature sources and professional judgment. From the literature sources the previously conducted criteria development studies are useful. There are also several ways to express habitat suitability in graphical forms in which the binary format is popular one. whereupon 1.0 represents most suitable and 0.0 represents not suitable(K D Bovee et al. 1998).

In this thesis we used category I(criteria based on literature sources) for the habitat suitability criteria calculation. The aims of this work are (I) The Hydraulic modelling of the rivers(Ticino & Adda) and calibration of manning's coefficient. (II) The development of habitat suitability curves (HSCs) with respect to velocity and depth for the species of interest and (III) The evaluation of WUA for the assessment of minimum environmental flow.

CHAPTER 2

LITERATURE REVIEW

Environmental issues has been considered more significant in many aspects of engineering decision-making process particularly in river management. There is an increasing effort to conserve functioning of rivers for human use as well as nature, therefore environmental flow assessment has been widely developed. Consciousness of that a specific measure of water needs to stay streaming in the waterway shapes another test for stream the executives as an additional interest is presently seeking the scant water asset. Universally this mindfulness is reflected in the Global Dialog on Water, Food and Environment, which has begun in the wake of the Second World Water Forum of March 2002.(Wahono et al. 2014)

Although the needs for irrigation, navigation, industry, and other water users are reasonably simple to estimate, there is still much disagreement regarding how the Environmental Flow requirements (EFR) should be defined. EFR originated as a commitment to guaranteeing a “minimum flow” in the river, which was frequently arbitrarily set at 10% of the major yearly flow.

The environmental flow assessment requires multidisciplinary study and integrated application of hydrology, hydraulics, river geomorphology, environmental science, biology, and so on. Flow regime, altered by socio-economic water use and dam constructions in many rivers, is believed to be the key point of environmental flow as the master variable of fluvial geomorphology and aquatic community evolution, as well as mass and energy exchanging between streamway and floodplain area and advanced hydraulic models provide powerful tools for numeric simulation of hydrological processes in regional water cycle(Hao et al. 2016)

The development of Environmental Flow Assessment (EFA) methods began in the late 1940s and was applied in the 1970s, mostly as a result of new environmental and freshwater regulations that coincided with the peak of the dam-building era in the United States. Outside of the United States, EFA methods did not acquire considerable traction until the 1980s or later. According to (Tharme 2003),Australia and South Africa are among the most advanced countries in terms of EFA development and application(Akter 2021)

The concept of e-flows has been around for more than 40 years (Acreman and Dunbar, 2004; Snelder et al., 2014; Tharme 2003), and it is extensively used across the world, but with considerable variations depending on the application. E-flows may be classified into two types based on the technique they use.

On the one hand, there are the traditional hydrologically based methods (e.g. minimum flow, flow percentiles (Tharme, 2003). This category contains easy-to-implement and basic techniques that may be used across broad regions but do not focus on any ecological variable, which is in some ways in opposition to the concept of e-flows. e-flows in this category are usually characterized as continuous flows throughout the year, ignoring the inter-annual flow variability that regulates species life stages (Stromberg et al., 2010)

On the other hand, physical habitat modelling approaches based on in-situ and experimental data to assess ideal environmental conditions for target species are known as micro-scale and mesoscale methodologies. In the scientific literature, several habitat suitability models are described. At the microscale, see PHABSIM (Ken D. Bovee 1982), RHYHABSIM (Jowett, 2010), RIVER2D (Steffler and Blackburn 2002), WHYSWESS (Yi, Wang, and Yang 2010), and CASiMIR (Muñoz-Mas et al. 2012),and at the mesoscale, see MesoHABSIM (Parasiewicz 2001),MesoCASiMIR PHABSIM and MesoHABSIM are the most commonly used and typical of these models.

Habitat-based models have been widely utilized to describe the connection between in-streamflow and habitat availability for diverse fish species, and hence the optimal or minimal flowrate(Fornaroli et al. 2016).

Although it is well known that fish and macroinvertebrates do not occupy any environment within the river regardless of hydraulics, they do show strong preferences for certain hydro morphological parameters such as water depth, current velocity, substrate size, and composition (Dolédec et al. 2007). Hydraulic techniques connect various hydraulic geometry characteristics of stream channels to discharge. The hydraulic geometry is based on surveyed cross-sections, which are used to calculate characteristics such as width, depth, velocity, and wetted perimeter. In situ observations, prediction using cross-section data and stage–discharge rating curves, Manning's or

Chezy's equations (Bovee, 1978), or computation of water surface profiles can all be used to determine variation in hydraulic geometry with discharge (M. Giugni1, N. Fontana2, G. Lombardi3 2008).

In Italy there are usually hydrologic or hydraulic-based methods to evaluate the flow requirements of controlled waterways without an explicit reference to biological data. These approaches generate essentially a functional connection between flux and simple hydraulic or river basin features(Vismara et al. 2001)

The hydrodynamic and biological components of Habitat Suitability Curves (HSC) evolution may be separated methodologically. The hydraulic component of HSC was obviously derived from gauging methods established by the early U.S. Geological Survey for irrigation. The origin and development of the biological component of HSC are less clear because much of the original documents were published in relatively obscure sources that are no longer available(Nestler et al. 2019)

Habitat suitability curves are the biological basis of habitat methods. The seasonal needs for distinct life stages can be described as habitat appropriateness, although this is not restricted to aquatic species. Hydraulic-habitat models relate the hydraulic habitat features of water depth and velocity, and substrate composition, to suitable habitat conditions for specific biota. The relationship between suitable habitat under differing flows is summarised in the combined habitat suitability index (CSI) and weighted usable area (WUA)(Kelly et al. 2015)

The weighted usable area is defined as the total surface area having a certain combination of hydraulic conditions, multiplied by the composite probability of use for that combination of conditions. This calculation is applied to each cell within the multidimensional matrix. This procedure roughly equates an area of marginal habitat to an equivalent area of optimal habitat. (Bovee and Cochnauer,1977).

WUA is also “roughly equivalent to the carrying capacity of a stream reach, based on physical conditions alone.” (Bovee,1978)

Weighted usable area has traditionally been calculated as the sum of stream surface area within a study site, normalized to square units (either feet or meters) per 1000 linear units, and weighted by multiplying area by habitat suitability variables (most often velocity, depth, and substrate or cover) that range from 0.0 to 1.0 each.(Payne 2003):

The weighted usable area for the reach is then calculated using the equation:

$$WUA_{Q,S} = \sum_{i=1}^{n} C_{i,s} * A_i$$

where the weighted usable area for the reach is specific to the flow, the species' life stage, and the reach to which it applies(Ken D. Bovee 1982).

WUA fluctuates when discharge (and water level) changes, indicating which flows are more 'accommodating' for fish (or other aquatic species). WUA comparisons across life stages of a species may indicate any possible ‘bottlenecks' in the development of fish from spawning to adulthood, which can help river managers determine what sorts of habitat restoration measures are needed and where they should be placed along a watercourse.

WUA illustrations often take the shape of line-drawing mosaics of stream cells as either two or three-dimensional trapezoids, the areas of which are defined by various weighted suitabilities for hydraulic or structural circumstances. The validity of the WUA concept has been vigorously debated ever since. Many researchers have demonstrated correlations between WUA and fish populations or biomass, especially when the effects of flow or recruitment over time are considered(Payne 2003)

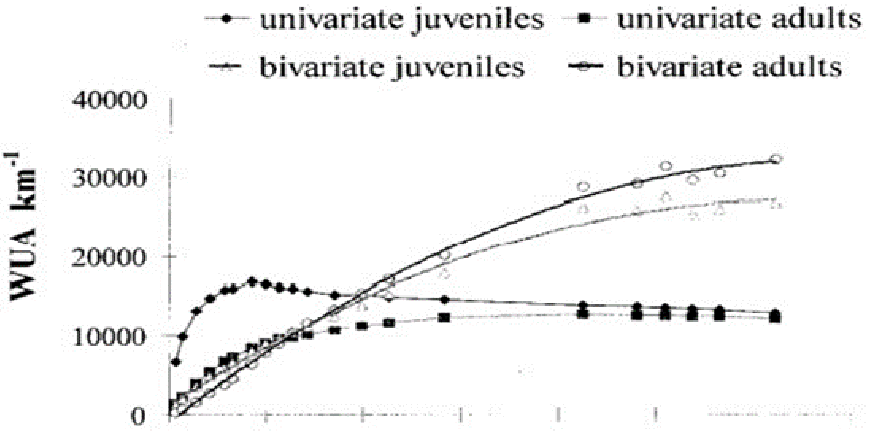


Fig 2.1 WUA versus discharge relationship for adult and juvenile brown trout(Vismara et al. 2001)

CHAPTER 3

DATA AND METHODS

3.1 STUDY AREA

The case study is in the Lombardy region of northern Italy, where the Ticino outflow of Lake Maggiore and the Adda outlet of Lake Como are the principal rivers. Both Adda and Ticino are tributaries of the Po River, and they host variety of species.

The Adda river starts in the Alps on the border of the Trentino-Alto Adige and Lombardy region, near Bormlo, and flows towards Lake Como. The province of Lecco is its exit from the lake. It is a tributary of the Po River, with its confluence point at Cremona, Lombardy. The river is 323 kilometers long.

Ticino is a tributary of the Po River that originates in Bedretto in Switzerland. It separates the regions of Lombardy and Piemonte. It is 248 kilometres long, with a point of confluence at Pavia.

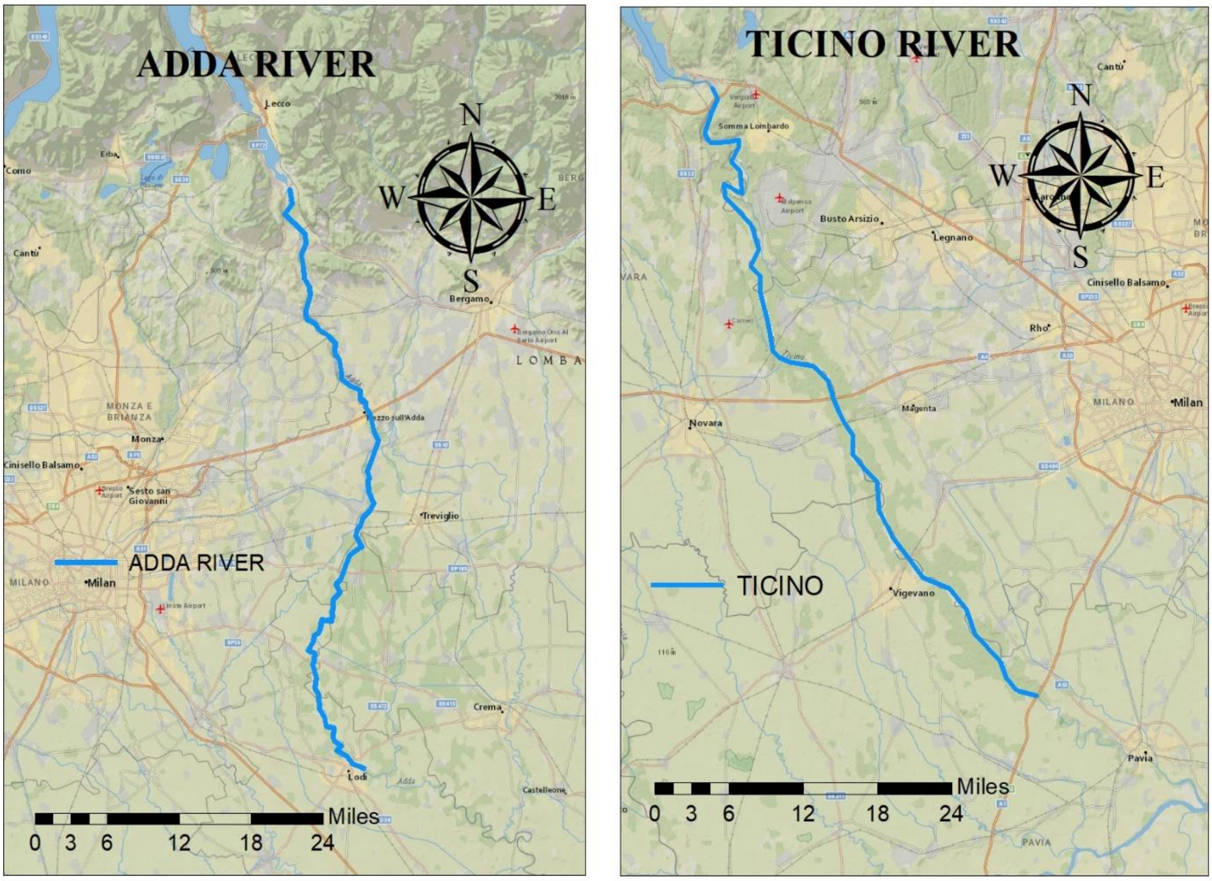
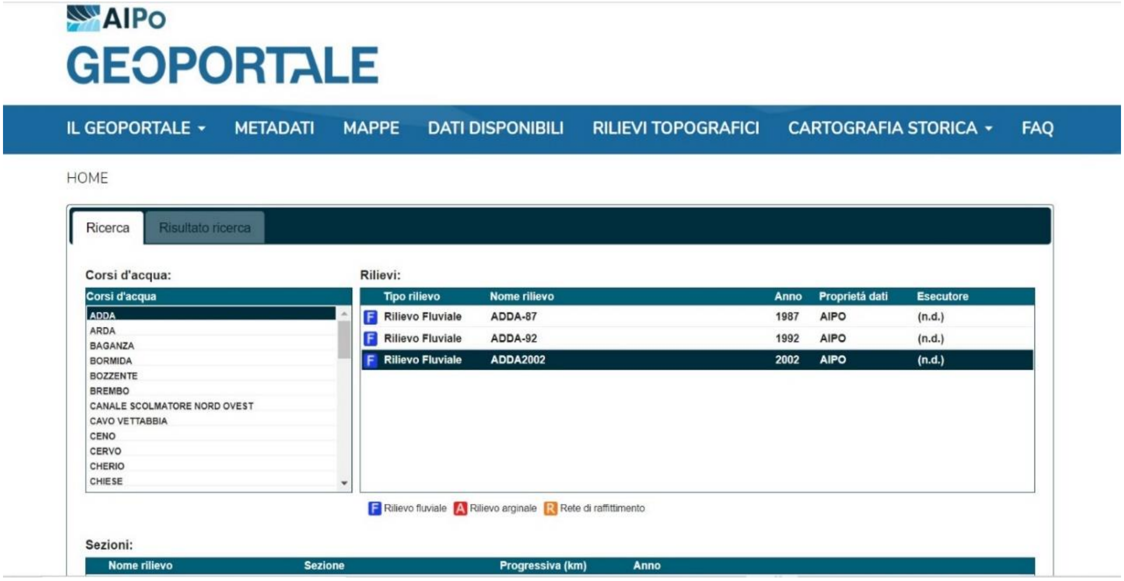


Fig 3.1 Study area maps

3.2 GEOMETRY DATA

The geometric data was retrieved from Agenzia Interregional per il Fiume po(ALPO) (http://geoportale.agenziapo.it/web/index.php/it/?option=com_aipografd3).For Adda river we used the cross section data from the survey of 2002 ADDA2002 and for the Ticino river data from the survey of 2004 TIC2004 were used.



Corsi d'acqua:

Corsi d'acqua
ADDA
ARDA
BAGANZA
BORMIDA
BOZZENTE
BREMBO
CANALE SCOLMATORE NORD OVEST
CAVO VETTABBIA
CENO
CERVO
CHERIO
CHIESE

Rilievi:

	Tipo rilievo	Nome rilievo	Anno	Proprietá dati	Esecutore
F	Rilievo Fluviale	ADDA-87	1987	AIPO	(n.d.)
F	Rilievo Fluviale	ADDA-92	1992	AIPO	(n.d.)
F	Rilievo Fluviale	ADDA2002	2002	AIPO	(n.d.)

F Rilievo fluviale A Rilievo arginale R Rete di raffittimento

Sezioni:

Nome rilievo	Sezione	Progressiva (km)	Anno

Fig 3.2 showing a screenshot of Geoportale website

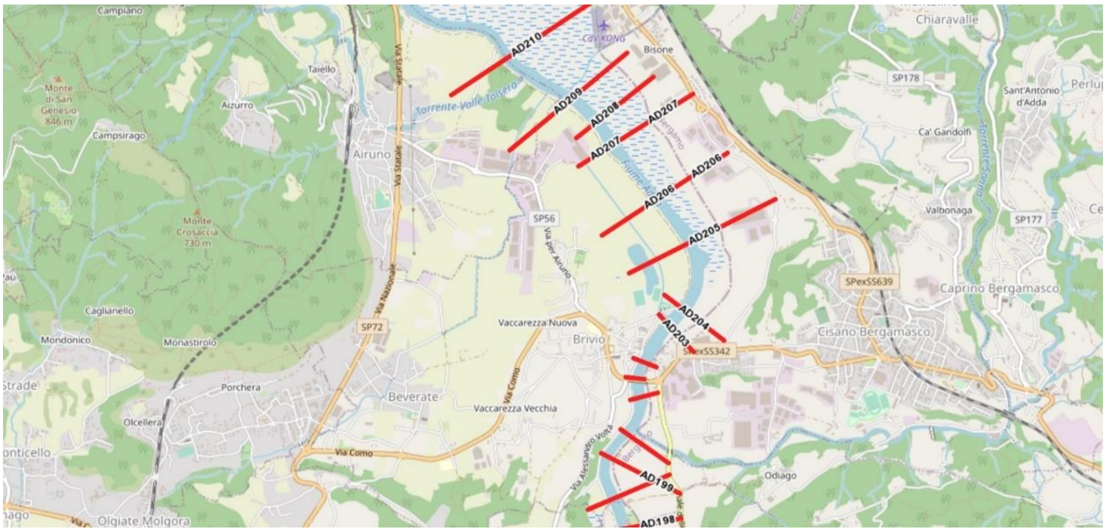


Fig 3.3 showing the crossection data of adda river

The geometric data is in the form of elevation and progressive of the crossection.

3.3 BRIDGES DATA

The information required for a bridge are: the river, reach, and river station IDs; a brief description of the bridge; the bridge deck; bridge abutments (if they exist); bridge piers (if the bridge has piers).

The bridges in the river reaches which influences the flow has been identified. For Ticino River 4 bridges have been identified and for adda 5.

The distance between the upstream section and bridge deck and height, width of the piers has been visually estimated from the satellite images.

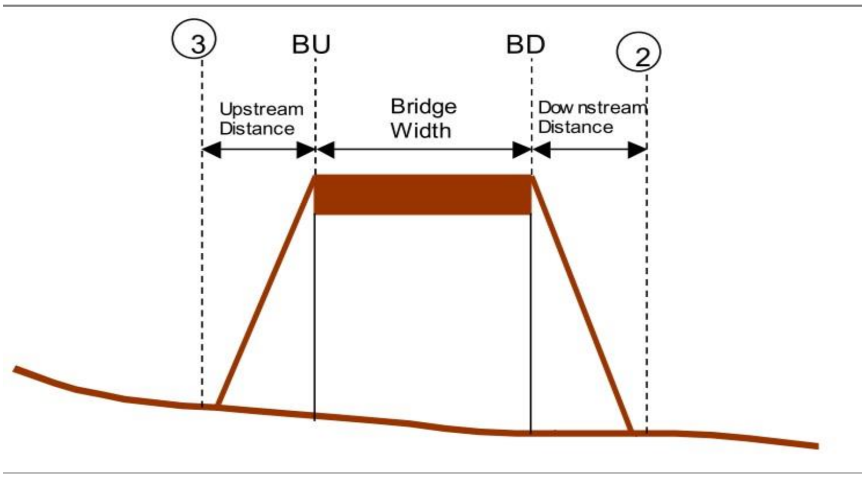
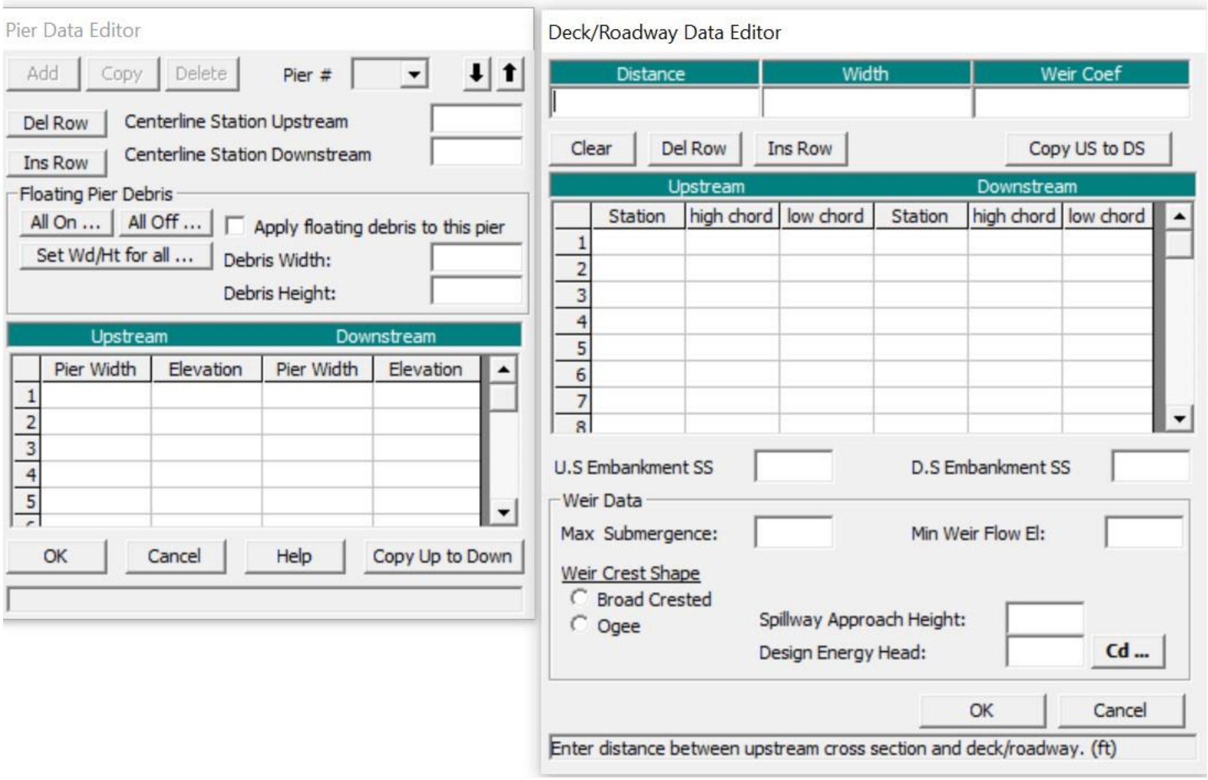


Fig 3.4 Example Bridge Profile with Upstream Distance, Bridge Width, and Downstream Distance(Gary W. Brunner n.d.)



Enter distance between upstream cross section and deck/roadway. (ft)

Fig 3.5 HEC-RAS bridge data editor

3.4 OBSERVED SECTIONS FOR THE CALIBRATION OF MANNING'S COEFFICIENT

For the initial simulations the values of roughness for main channel, left and right banks are chosen according to the topography and given pictures of the sections. The values of main channel are obtained from the "Verified Roughness Characteristics of Natural Channels" provided by USGS website.

The water surface levels from three sections from two rivers have been observed for the calibration of manning's coefficient .

TICINO	**ADDA**
Vigevano(Ponte Sul Vigevano) section33	Rivolta d' Adda (section 140)
	Ponte napoleone Bonaparte (via X Maggio) section 103

Table 3.1 Observed sections for the calibration of manning's coefficient

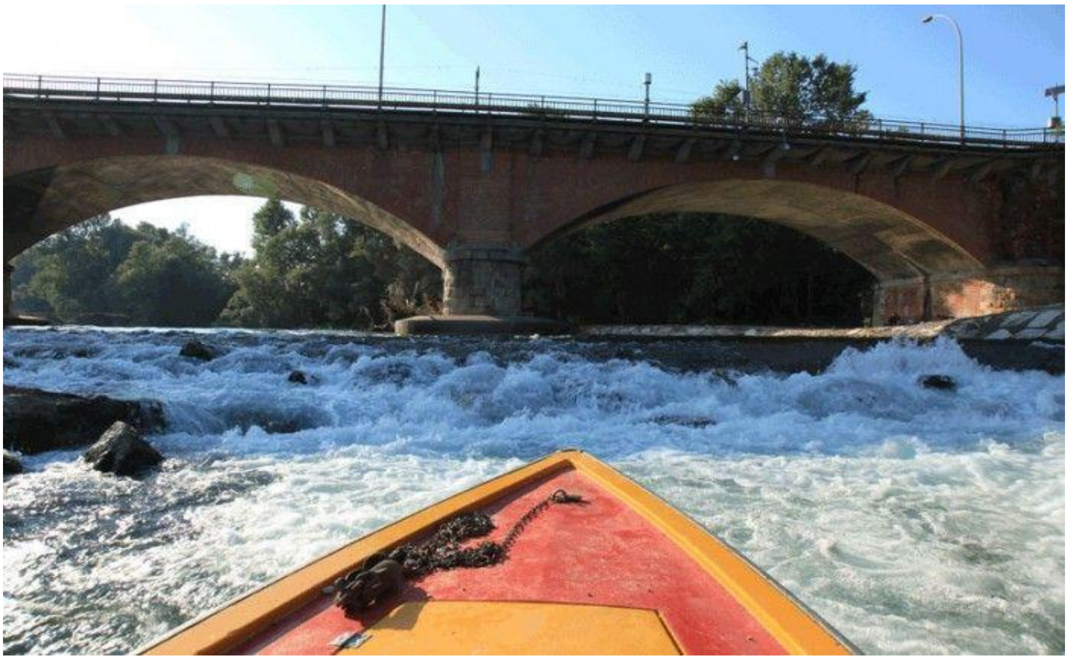


Fig.3.6 ponte sul Vigevano(section tic_33) Ticino River

Fig.3.7 Rivolta d' Adda (section ADD140) ADDA River

Fig.3.8 ponte napoleone Bonaparte (section ADD103) ADDA River

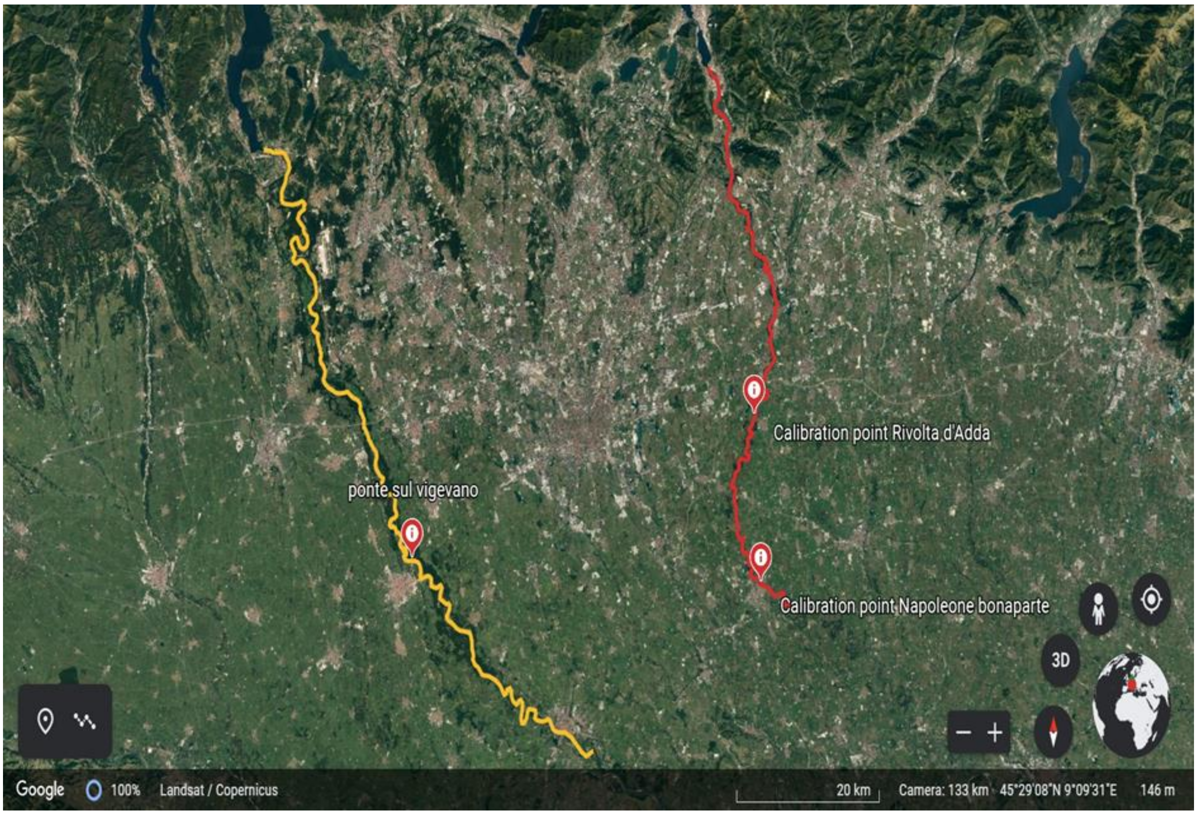


Fig.3.9 map showing the calibration points of Adda(red) and Ticino(yellow) river

3.5 CHANNEL DIVERSIONS FROM THE RIVERS

Agricultural and navigational water diversion dates back to at least 13th century. Diversion works take more than 50% of the average yearly runoff from adda river Running around 140,000 hectares of highly grown crops, Irrigation diversions are more varied and focused throughout the summer(Salmaso et al. 2018).The discharges from these sections with diversions were used in hydraulic model as flow change location

ADDA	TICINO
Adda Serio	Canale Regina Elena
Naviligio Martesana	Canale villoresi
Canale Retorto	Naviligio Grande
Canale Muzza	
Roggia rivoltana	
Canale vacchelli	

Table 3.2 Diverted channels for irrigation purposes from Ticino And Adda River

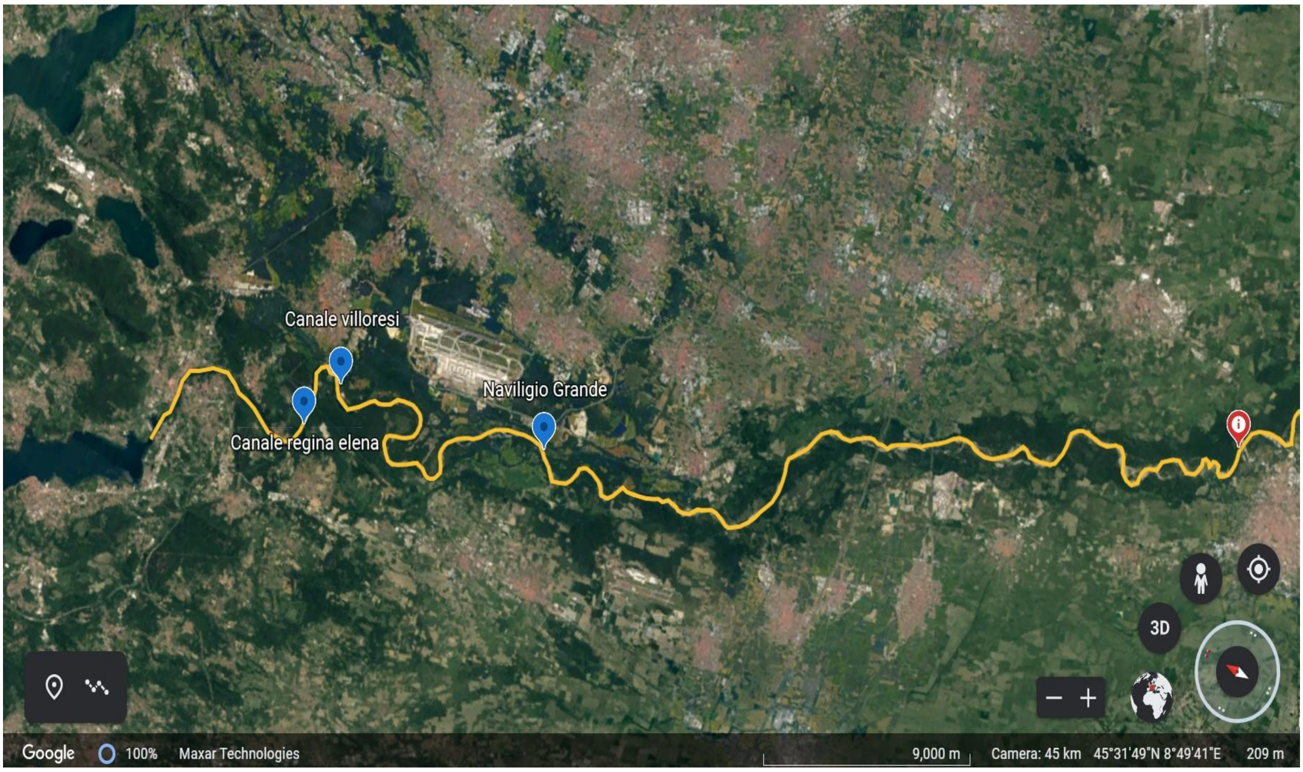


Fig. 3.10 map showing the Diversion points Ticino River

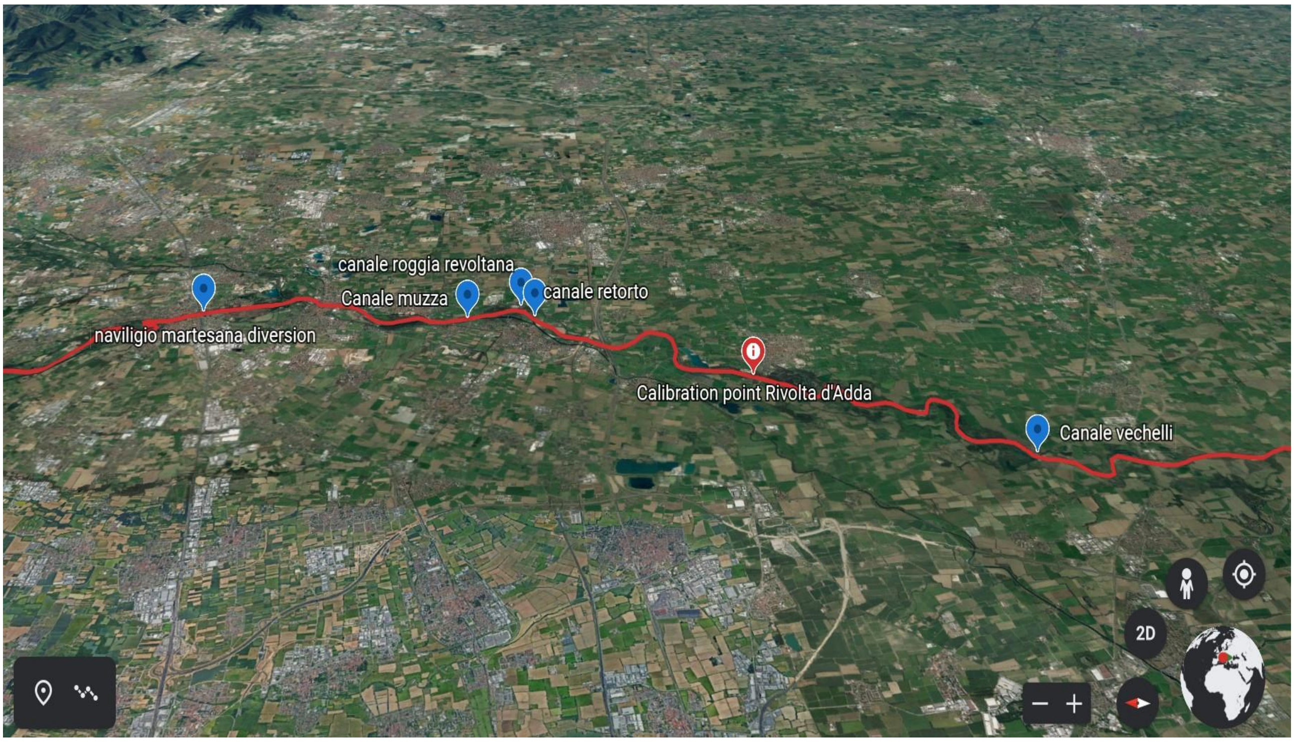


Fig. 3.11 map showing the Diversion points Adda River

3.6 DISCHARGE DATA AND FLOW DURATION CURVES

The discharge data for these diversion channels were obtained from were obtained by means of the hydrological model Poli-Hydro(Aili et al. 2019).A significant inquiry regularly posed with regards to waterways is 'which level of time streams surpass (or not surpass) a given value (e.g., 100 cfs)?' It might be imperative to respond to that inquiry to decide the level of time when the stream is too low to even consider supporting a specific fish species. The extent of time any given stream surpass a given value can be determined by generating a flow duration curve for the stream.

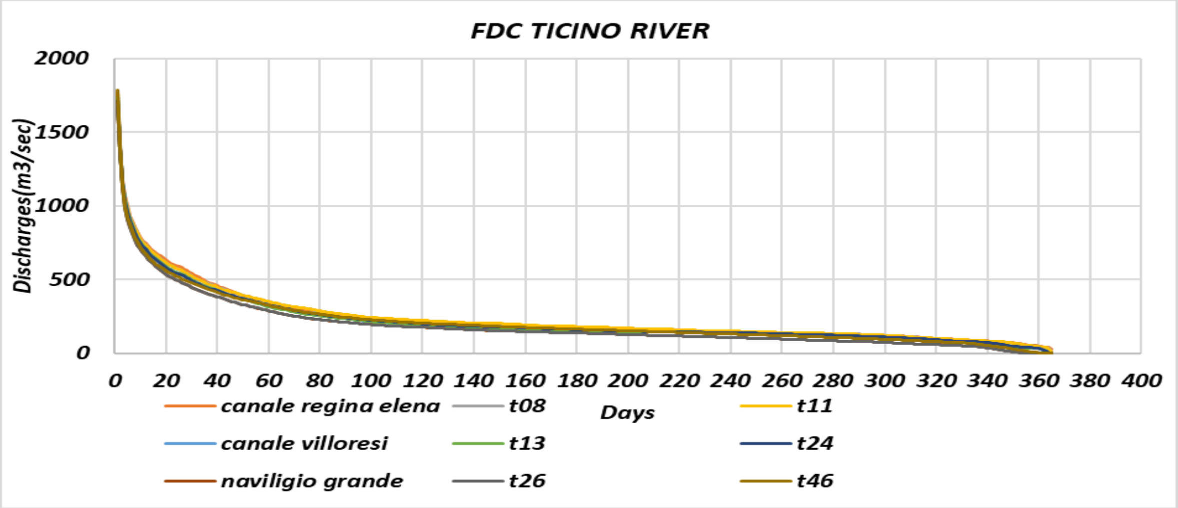


Fig 3.12 flow duration curve Ticino river

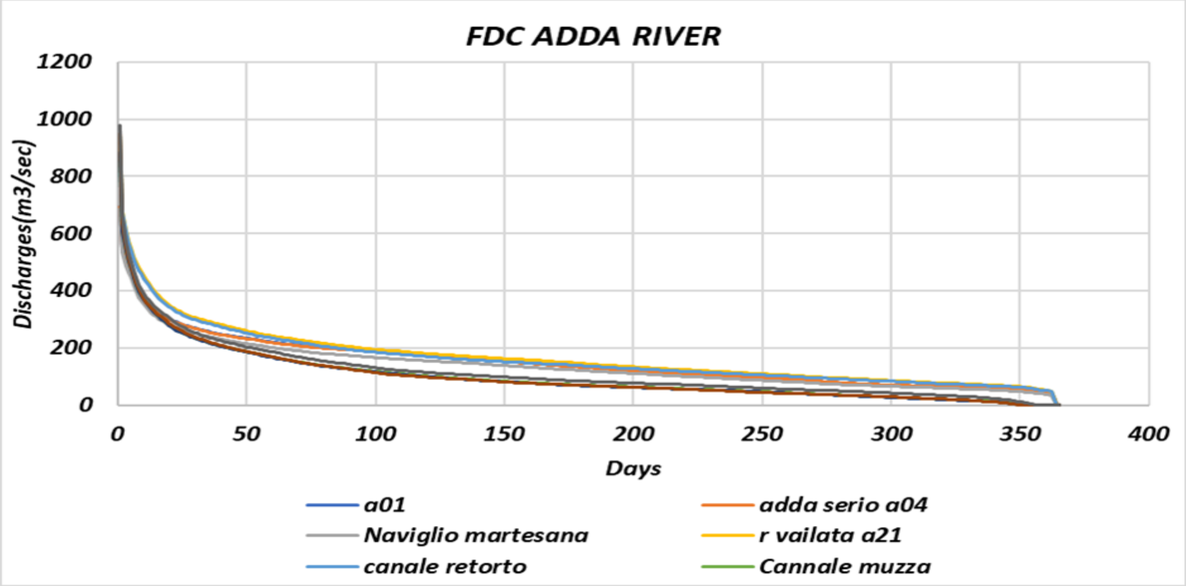


Fig 3.13 flow duration curve Adda river

Flow duration curves were generated for the Ticino and adda rivers to determine the days with low flows throughout the year.

3.7 IDENTIFICATION OF FISH SPECIES

We identified the species of fishes present in our study reaches from Fish map of Lombardy region (Carta ittica Regionale lombardia), elaborated within the plan for waterways safety of 2016(Piano di tutela delle Acque (PTA) of 2016).

SECTIONS (UPSTREAM TO DOWNSTRAM)		***SPECIES OF FISHES***
FROM	TO	Trota marmorata e/o Temolo
ADD220	ADD217	
ADD216	ADD187_03	Ciprinidi limnofili
ADD187_02	ADD104	Trota marmorata e/o Temolo
ADD103	ADD101	Ciprinidi Reofili

Table 3.3 species of fishes in Adda river study reach

SECTIONS (UPSTREAM TO DOWNSTRAM)		***SPECIES OF FISHES***
FROM	TO	Ciprinidi Reofili
Tic_sez83_1	Tic_sez57	
Tic_sez53	Tic_sez21	Trota marmorata e/o temolo

Table 3.4 species of fishes in Ticino river study reach

Marble trout's are freshwater fish regularly found in the headwater of waterways and in little mountain streams with gravelly beds (Chiesa et al., 2016; Marchi et al., 2016). They, as most other trout, search out openings in the riverbed close to the bank to hide in. They prefer cold, fast flowing waters (Cuvier et al. 1829).

Fig 3.14 Marble trout

Temolo are found principally in fresh water natural surroundings. However, some also can be found into brackish water, a mixture of salt and freshwater. Generally, this species prefers habitats with clean, clear water. They live in creeks, streams, and rivers with running currents. You can also sometimes find these fish in lakes, ponds, and other similar habitats.

Fig. 3.15 Temolo

Ciprinidi reofili which is most commonly found in these rivers is Italian barbel and also known as barbus barbus. As barbel are rheophilous, they prefer areas of relatively fast water compared with other cyprinid fishes (Huet, 1949).

Fig. 3.16 Ciprinidi reofili (Barbus Barbus)

Ciprinidi limnofili lives in lakes, trenches, and slow-streaming waterways. They generally lives in rivers (especially in the lower reaches) , in nutrient-rich lakes, ponds with muddy bottoms and plenty of algae. It can also be found in brackish sea waters.

Fig. 3.17 Ciprinidi Limnofili

3.8 HYDRAULIC MODELLING

In this work we used HEC-RAS 1D for the hydraulic simulations. HEC-RAS is a software system that is meant to be used interactively in a multi-tasking, multi-user network environment. A graphical user interface (GUI), distinct hydraulic analysis components, data storage and administration capabilities, visuals and reporting tools are all part of the system.(Gary W. Brunner n.d.)

There are five primary steps in creating a HEC-RAS model.

1) Starting a new project
2) Entering geometric data
3) Entering flow data and boundary conditions
4) Performing the hydraulic calculations
5) Viewing and publishing results

3.8.1 FUNDAMENTAL HYDRAULIC EQUATIONS

The fundamental equations that controls the 1-D, steady-state, gradually-varying flow analysis in HEC-RAS are continuity equation, energy equation, and flow resistance equation.

The continuity equation characterizes a discharge as steady and continuous(Chow 1959)

$$\boldsymbol{Q = A_1V_1 = A_2V_2} \qquad \textbf{(1)}$$

A1 = cross-sectional area normal to the direction of flow at the downstream cross section (m2); A2 = cross-sectional area normal to the direction of flow at the upstream cross section (m2); Q = discharge (m3); V1 = average velocity at the downstream cross section (m/s); and V2 = average velocity at the upstream cross section (m/s).

Using the continuity equation, the average velocity is expressed in terms of discharge and cross-sectional area

$$\boldsymbol{\bar{V} = \frac{Q}{A}} \tag{2}$$

A = cross-sectional area normal to the direction of flow (m2); Q = discharge (m3); and

v = average velocity (m/s)

Total energy can be calculated as total head in m of water at every point along an open-channel system (Chow 1959).The energy equation is used to compute the total head of water. The total head of water is calculated using the energy equation as the sum of the bed elevation, average flow depth, and velocity head at a cross section.

$$\boldsymbol{H = z + y + \frac{\alpha v^{-2}}{2g}} \tag{3}$$

α = kinetic energy correction coefficient; g = acceleration of gravity (m/s2); H = total head of water (m); v = average velocity at a cross section (m/s); y = flow depth at a cross section (m); and z = bed elevation at a cross section (m)

To properly estimate the velocity head at a cross section, the kinetic energy correction coefficient is multiplied by the velocity head. The true velocity head at a cross section is often higher than the projected velocity head at a cross section based on the average velocity(Chow 1959).

The flow resistance equation utilizes a form of Manning's equation that applies average roughness to a cross section's wetted perimeter (United States Army Corps of Engineers (USACE), 2001a)

$$\boldsymbol{Q = KS_f^{\frac{1}{2}}} \tag{4}$$

K = channel conveyance (m); Q = discharge (m); and Sf = friction slope (m/m).

Conveyance at a cross section is obtained using Equation

$$\boldsymbol{K = \frac{\emptyset}{n} AR^{\frac{2}{3}}} \tag{5}$$

A = cross-sectional area normal to the direction of flow (m2); Φ = unit conversion (Eng= 1.486 and SI = 1.000); K = channel conveyance (m); n = roughness coefficient; R = hydraulic radius (m).

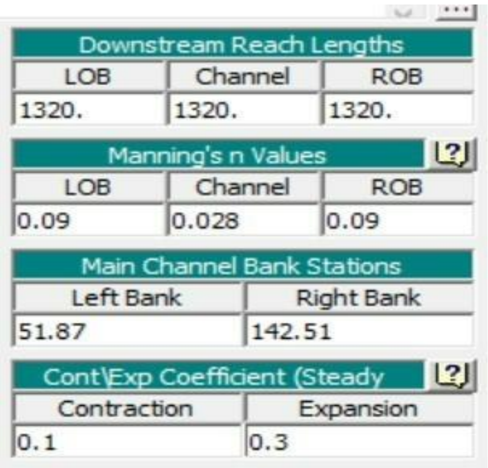
In a 1-D, steady-state, gradually-varying flow study, expansion and contraction losses are referred to as minor loss along a reach. Energy loss owing to variations in cross-sectional form throughout the reach is connected to small expansion and contraction losses. Appropriate coefficients are used to account for energy losses owing to expansion and contractions along a reach. Once a suitable coefficient has been established, in order to compute the energy loss, the coefficient is multiplied by the velocity head.

$$\boldsymbol{h_e} = \boldsymbol{C_e}\left(\frac{\alpha_2 \bar{v}_2^2}{2g} - \frac{\alpha_1 \bar{v}_1^2}{2g}\right) \tag{6}$$

Where α1 = kinetic energy correction coefficient at the downstream cross section;α2 = kinetic energy correction coefficient at the upstream cross section; Ce = coefficient of expansion; g = acceleration of gravity (m/s2); he = minor loss due to channel expansion at a cross section (m); v1 = average velocity at the downstream cross section (m/s); and v 2 = average velocity at the upstream cross section (m/s).

$$\boldsymbol{h_c} = \boldsymbol{C_e}\left(\frac{\alpha_2 \bar{v}_2^2}{2g} - \frac{\alpha_1 \bar{v}_1^2}{2g}\right) \tag{7}$$

where: α1 = kinetic energy correction coefficient at the downstream cross section; α2 = kinetic energy correction coefficient at the upstream cross section;Cc = coefficient of contraction; g = acceleration of gravity (m/s2); hc = minor loss due to channel contraction at a cross section (m); v1 = average velocity at the downstream cross section (m/s); and v 2 = average velocity at the upstream cross section (m/s).



Downstream Reach Lengths

LOB	Channel	ROB
1320.	1320.	1320.

Manning's n Values

LOB	Channel	ROB
0.09	0.028	0.09

Main Channel Bank Stations

Left Bank	Right Bank
51.87	142.51

Cont\Exp Coefficient (Steady

Contraction	Expansion
0.1	0.3

Fig 3.18 Contraction and expansion coefficients that HEC-RAS uses

3.8.2 STANDARD STEP METHOD ALGORITHM IN HEC-RAS

One of the programmed algorithms in HEC-RAS is the Standard step approach. HEC-RAS iteratively generates a water-surface profile and energy grade line starting with the most downstream cross section if the flow is subcritical. HEC-RAS creates a water-surface profile and energy grade line starting with the most upstream cross section if the flow is supercritical.

A known boundary condition is input by the user to begin the iterative operation

In HEC-RAS, there are four alternatives for establishing a single boundary condition.

1) known water-surface elevation;
2) critical depth;
3) normal depth; and
4) rating curve

When Fr = 1, flow depth is defined as the critical depth. The depth that corresponds to uniform flow is known as normal depth (Chow 1959).After the user enters the bed slope in downstream of the study reach, the normal depth is computed. For the normal depth, bed slope is equal to energy slope that's why it's used in flow resistance equation to calculate normal depth (USACE, 2001a).

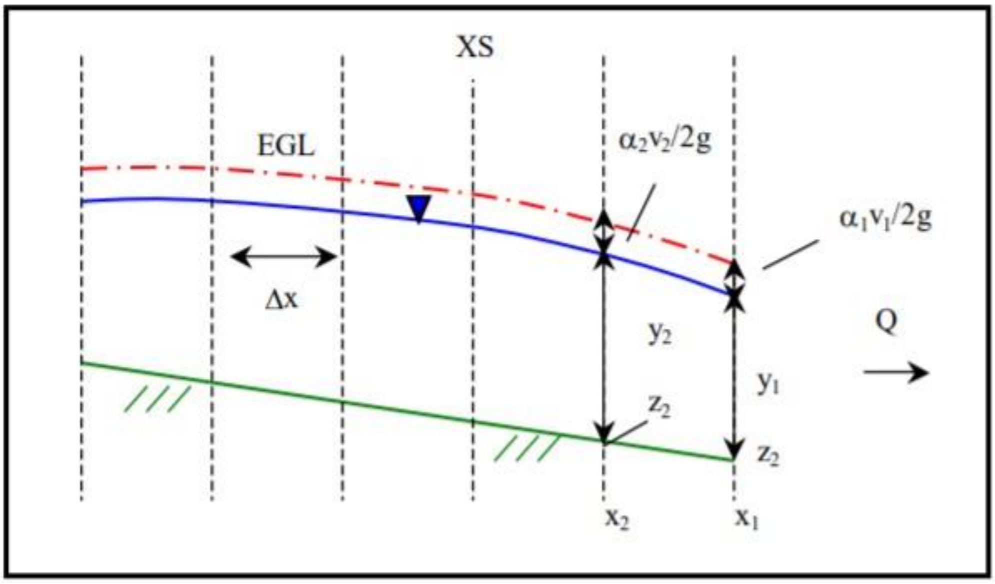


Fig 3.19 Standard step method(Kristin E.et al 2005)

3.9 HABITAT SUITABILITY INDICIES

calculating the suitability indices for marble trout we used the suitability curves(univariate) provided by (Vismara et al. 2001). The life stages juvenile and adult are also covered. Depth suitability curves of both adults and juveniles rises from approximately 5–10 cm to an optimum of 1.0 at 90–100 cm. Water velocity suitability curves calculated for both life-stages showed optimum values for low current velocities (<20 cm s−1)(Vismara et al. 2001).

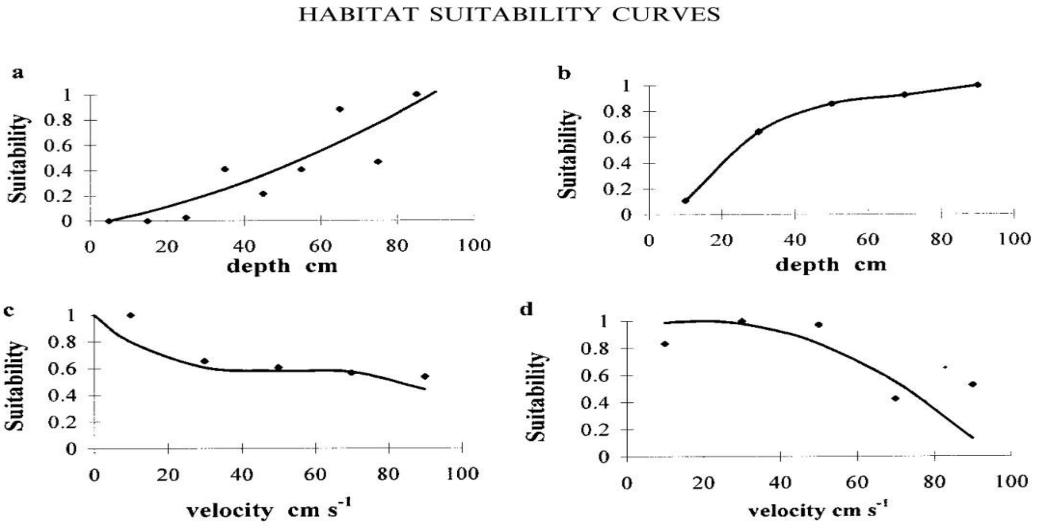


Fig .3.20 Suitability curves from(Vismara et al. 2001)

$$\text{Adult curve for depth(a) } S.I. = 0.0000639 \times d^2 + 0.0059068 \times d - 0.0059068;$$

$$\text{Juvenile curve for depth(b) } S.I. = 3.4056E - 06 \times d^3 - 0.0007006 \times d^2 + 0.05021 \times d - 0.326958;$$

$$\text{Adult curve for velocity(c) } S.I. = -3.0003E - 06 \times v^3 + 0.000474845 \times v^2 - 0.024660825 \times v + 1;$$

$$\text{Juvenile curve for velocity(d) } S.I. = -0.000170068 \times v^2 + 0.00629252 \times v + 0.942176871;$$

Similarly, for the second specie of interest (barbus barbus), we used the curves provided by (Rambaldi et al. 1997). We interpolated the points from these curves by making polynomial regressions.

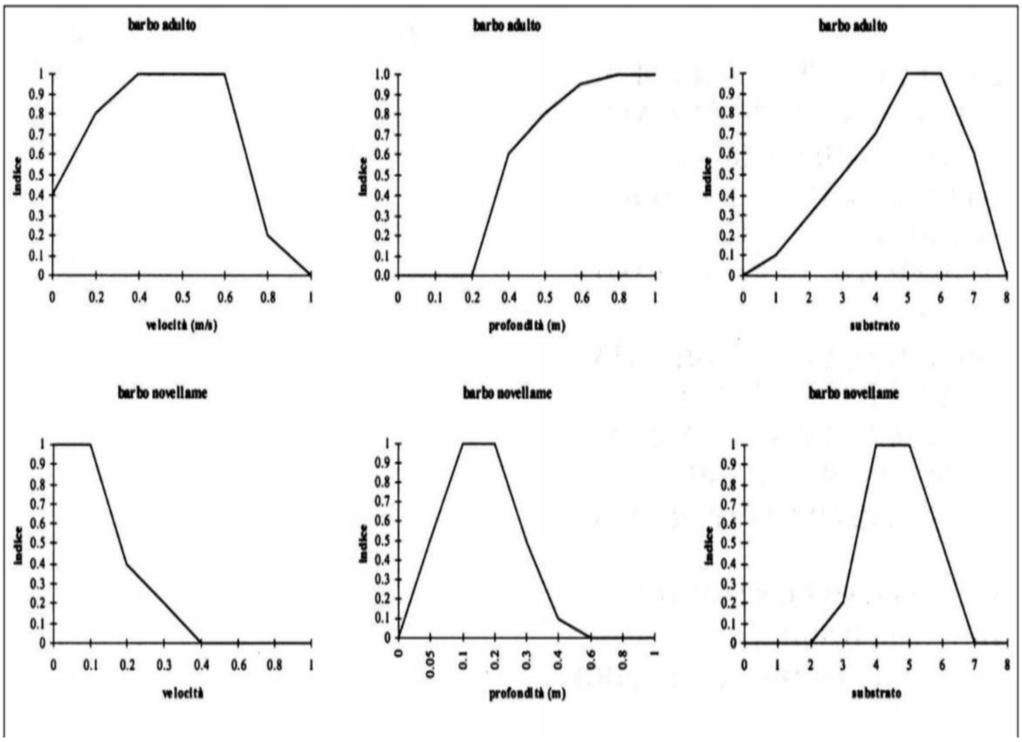


Fig .3.21 Suitability curves from(Rambaldi et al. 1997)

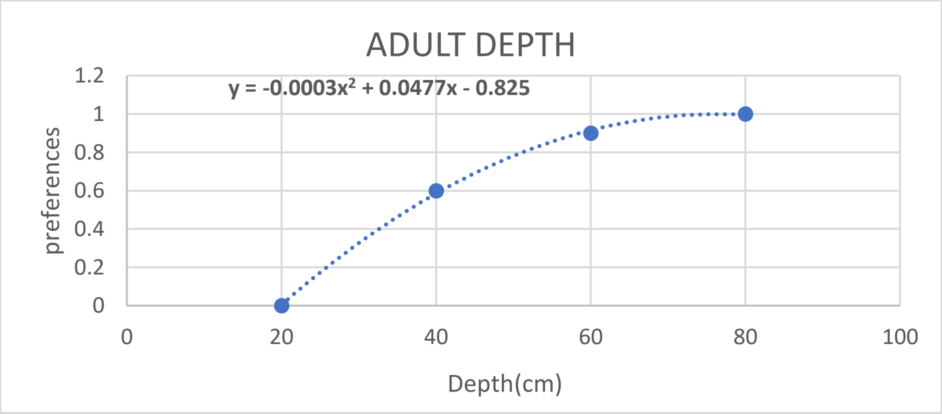


Fig .3.22 Adult polynomial regression for depth Barbus Barbus

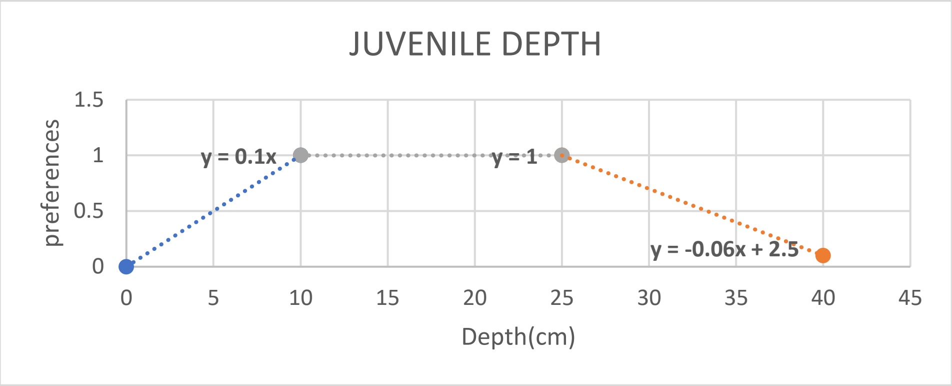


Fig .3.23 Juvenile polynomial regression for depth Barbus Barbus

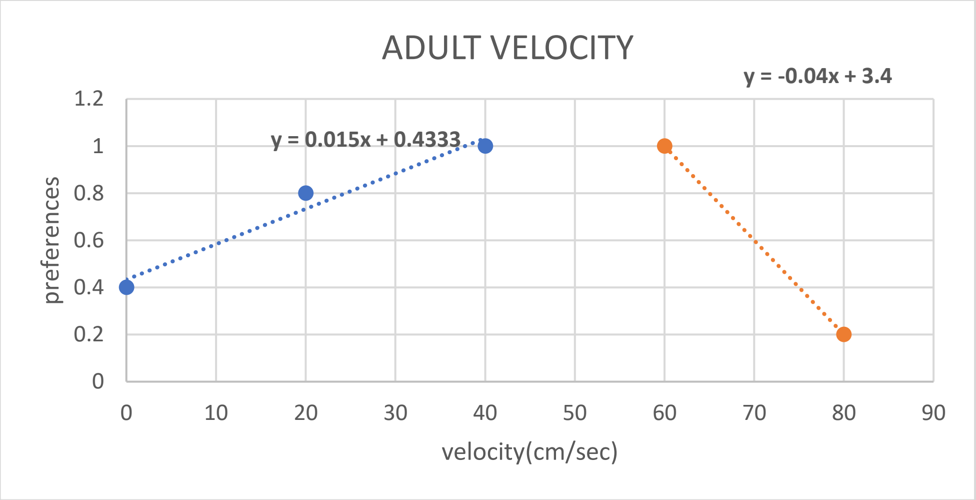


Fig .3.24 Adult polynomial regression for Velocity Barbus Barbus

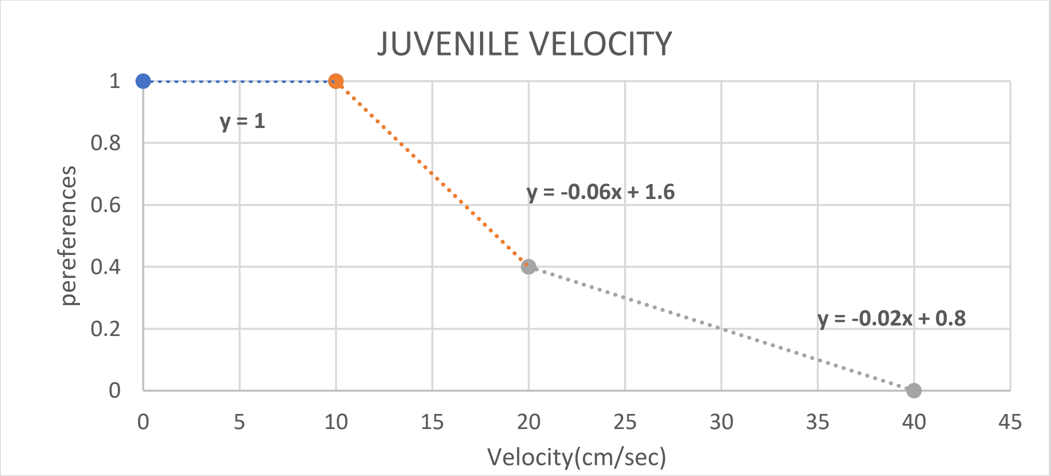


Fig .3.21 Juvenile polynomial regression for Velocity Barbus Barbus

The depth suitability is optimum at (<60cm) for adults and for juvenile it’s in between 10cm to 25 cm after 25cm of depth the suitability starts decreasing.

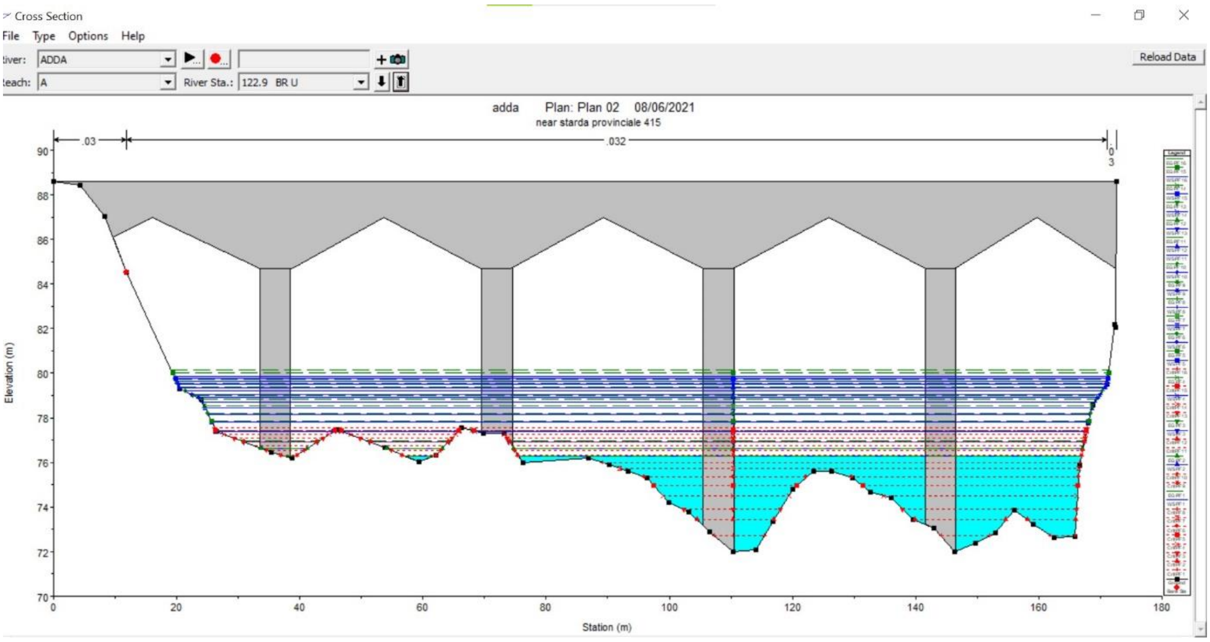
Water velocity suitability for adult barbus barbus is optimum from 40cm/sec to 60cm/sec, while for the juvenile the optimum value is at low flow rates up to 10cm/sec (Rambaldi et al. 1997).

CHAPTER 4

RESULTS

4.1 HEC-RAS 1D HYDRAULIC MODEL

The hydraulic modelling was initiated by entering the geometric data of the cross sections, initially the Manning's coefficients were entered from the USGS website and the steady state flow analysis was simulated and then for the calibration of the model the observed and simulated water surface was compared. Fig 4.1 shows a typical crossection after steady flow simulation.



iver: ADDA

each: A

River Sta.: 122.9 BR U

Fig 4.1 crossection after steady state simulation using 14 flow profiles

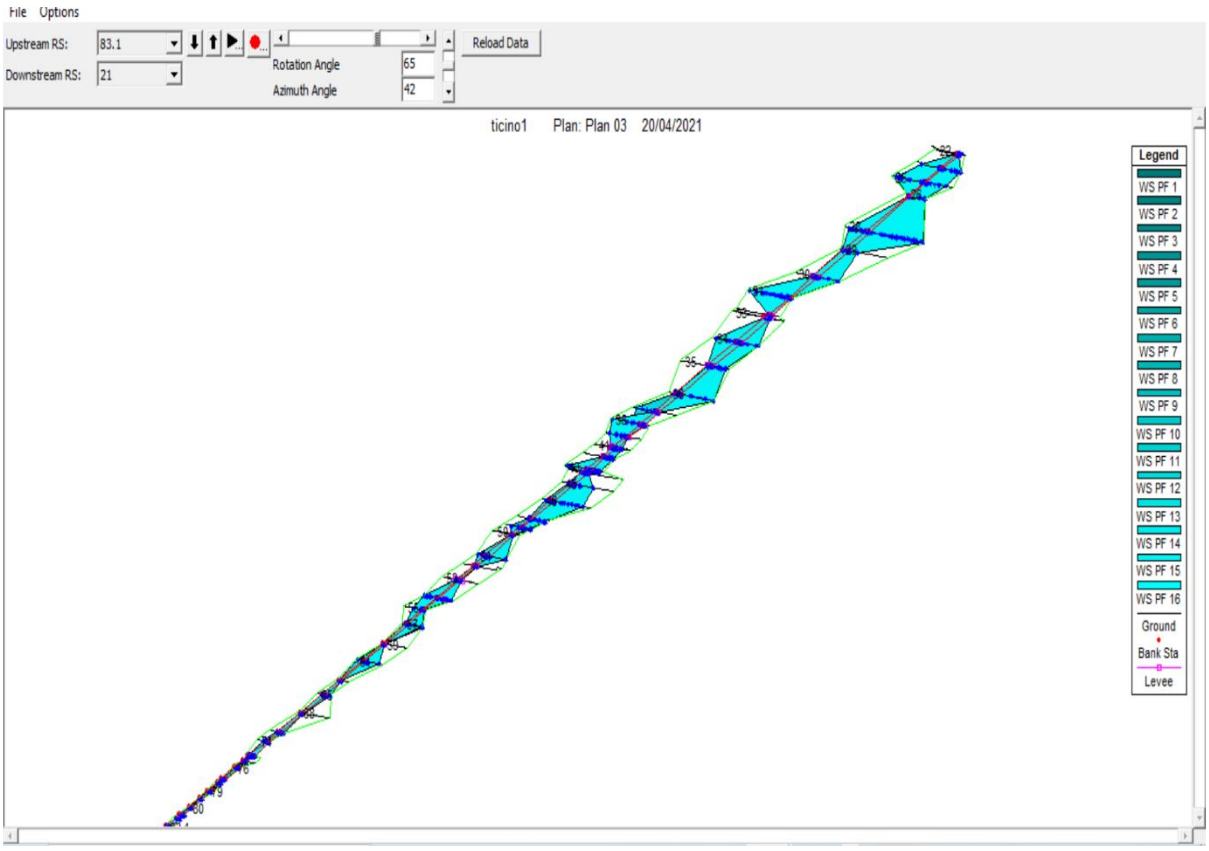
In our case the calibration of model was not straight forward due the immediate hydraulic jumps on downstream of the observed sections.

For the Adda river the calibration at the rivolta d'adda station is ok upstream of the bridge.Wherease for the Lodi station the modelled level is approximately 30cm higher than the observed one, but the Manning coefficient that we put is consistent with photos.

For Ticino the calibration of Manning coefficient in the section 33 provides acceptable results if we consider the mean value between upstream and downstream the bridge (For example, for Q 200m3/s the observed level is 83.75 mslm and if we consider the mean level before and after the bridge we obtain 83.7 mslm, so considering all the problems related to the flow in that section also due to the presence of the hydraulic jump it can be accepted.

After calibration we get the manning’s coefficient for Ticino and adda0.033 and 0.032 respectively.

Fig 4.2 and 4.3 shows the 3D multiple profile view of Ticino and Adda rivers from HEC-RAS 1D modelling.



Upstream RS: 83.1

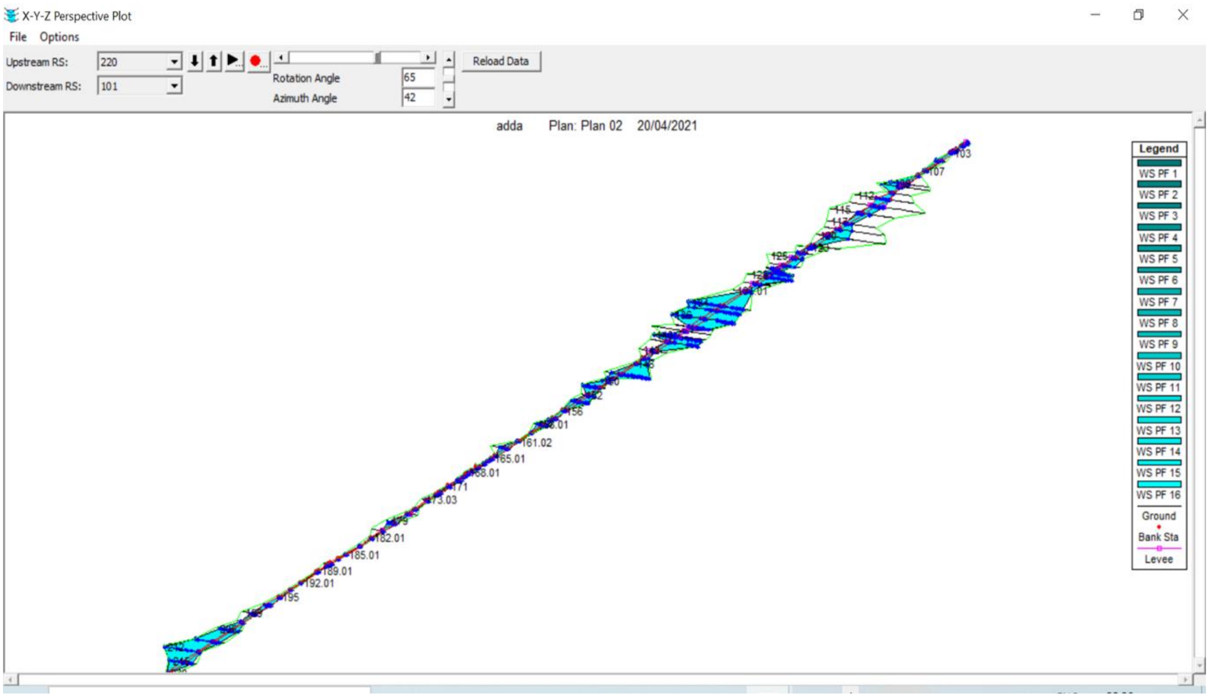
Downstream RS: 21

Rotation Angle 65

Azimuth Angle 42

ticino1 Plan: Plan 03 20/04/2021

Fig 4.2 3D view multiple profile Ticino River



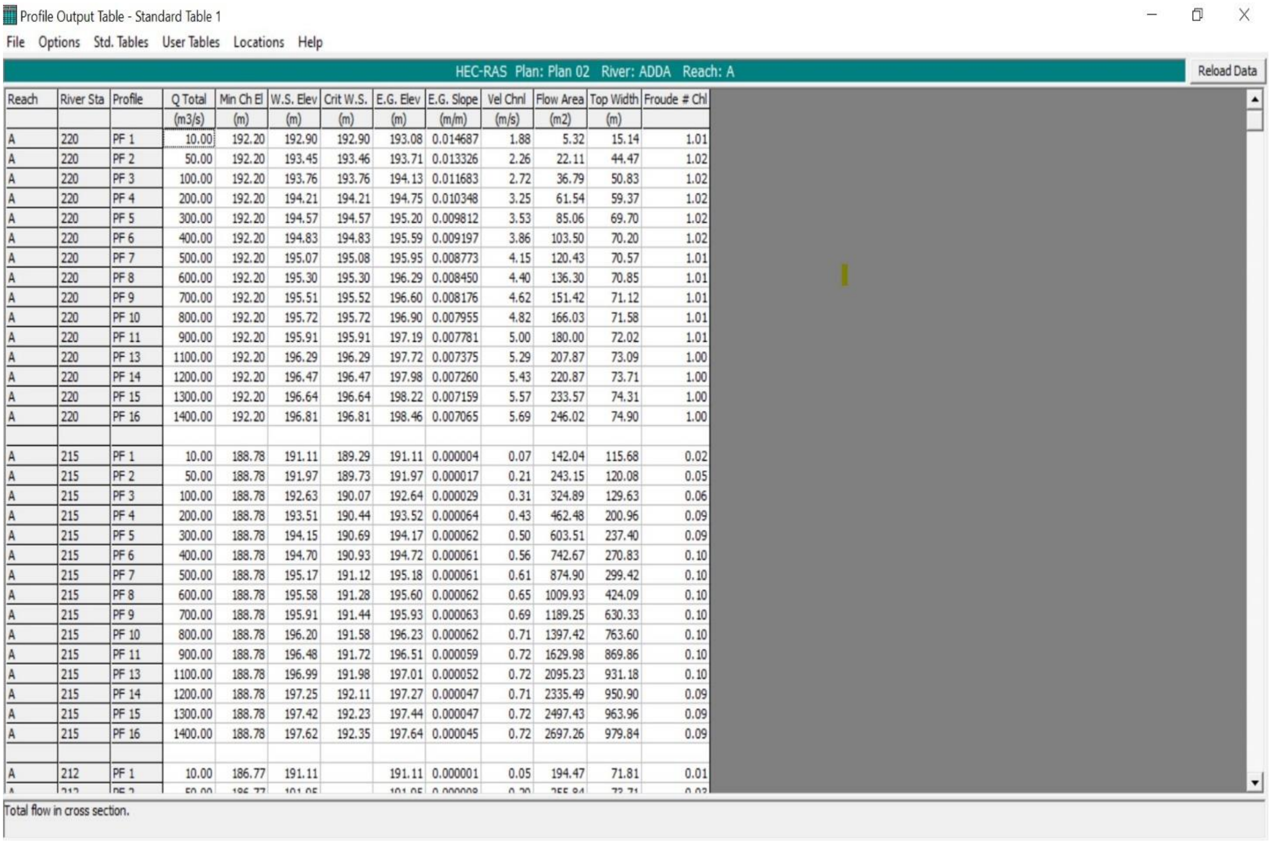
Upstream RS: 220

Downstream RS: 101

Rotation Angle 65

Azimuth Angle 42

Fig 4.3 3D View multiple profile Adda River



HEC-RAS Plan: Plan 02 River: ADDA Reach: A

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
A	220	PF 1	10.00	192.20	192.90	192.90	193.08	0.014687	1.88	5.32	15.14	1.01
A	220	PF 2	50.00	192.20	193.45	193.46	193.71	0.013326	2.26	22.11	44.47	1.02
A	220	PF 3	100.00	192.20	193.76	193.76	194.13	0.011683	2.72	36.79	50.83	1.02
A	220	PF 4	200.00	192.20	194.21	194.21	194.75	0.010348	3.25	61.54	59.37	1.02
A	220	PF 5	300.00	192.20	194.57	194.57	195.20	0.009812	3.53	85.06	69.70	1.02
A	220	PF 6	400.00	192.20	194.83	194.83	195.59	0.009197	3.86	103.50	70.20	1.02
A	220	PF 7	500.00	192.20	195.07	195.08	195.95	0.008773	4.15	120.43	70.57	1.01
A	220	PF 8	600.00	192.20	195.30	195.30	196.29	0.008450	4.40	136.30	70.85	1.01
A	220	PF 9	700.00	192.20	195.51	195.52	196.60	0.008176	4.62	151.42	71.12	1.01
A	220	PF 10	800.00	192.20	195.72	195.72	196.90	0.007955	4.82	166.03	71.58	1.01
A	220	PF 11	900.00	192.20	195.91	195.91	197.19	0.007781	5.00	180.00	72.02	1.01
A	220	PF 13	1100.00	192.20	196.29	196.29	197.72	0.007375	5.29	207.87	73.09	1.00
A	220	PF 14	1200.00	192.20	196.47	196.47	197.98	0.007260	5.43	220.87	73.71	1.00
A	220	PF 15	1300.00	192.20	196.64	196.64	198.22	0.007159	5.57	233.57	74.31	1.00
A	220	PF 16	1400.00	192.20	196.81	196.81	198.46	0.007065	5.69	246.02	74.90	1.00
A	215	PF 1	10.00	188.78	191.11	189.29	191.11	0.000004	0.07	142.04	115.68	0.02
A	215	PF 2	50.00	188.78	191.97	189.73	191.97	0.000017	0.21	243.15	120.08	0.05
A	215	PF 3	100.00	188.78	192.63	190.07	192.64	0.000029	0.31	324.89	129.63	0.06
A	215	PF 4	200.00	188.78	193.51	190.44	193.52	0.000064	0.43	462.48	200.96	0.09
A	215	PF 5	300.00	188.78	194.15	190.69	194.17	0.000062	0.50	603.51	237.40	0.09
A	215	PF 6	400.00	188.78	194.70	190.93	194.72	0.000061	0.56	742.67	270.83	0.10
A	215	PF 7	500.00	188.78	195.17	191.12	195.18	0.000061	0.61	874.90	299.42	0.10
A	215	PF 8	600.00	188.78	195.58	191.28	195.60	0.000062	0.65	1009.93	424.09	0.10
A	215	PF 9	700.00	188.78	195.91	191.44	195.93	0.000063	0.69	1189.25	630.33	0.10
A	215	PF 10	800.00	188.78	196.20	191.58	196.23	0.000062	0.71	1397.42	763.60	0.10
A	215	PF 11	900.00	188.78	196.48	191.72	196.51	0.000059	0.72	1629.98	869.86	0.10
A	215	PF 13	1100.00	188.78	196.99	191.98	197.01	0.000052	0.72	2095.23	931.18	0.10
A	215	PF 14	1200.00	188.78	197.25	192.11	197.27	0.000047	0.71	2335.49	950.90	0.09
A	215	PF 15	1300.00	188.78	197.42	192.23	197.44	0.000047	0.72	2497.43	963.96	0.09
A	215	PF 16	1400.00	188.78	197.62	192.35	197.64	0.000045	0.72	2697.26	979.84	0.09
A	212	PF 1	10.00	186.77	191.11		191.11	0.000001	0.05	194.47	71.81	0.01

Total flow in cross section.

Fig 4.4 output table HEC-RAS 1D steady state simulations

The obtained water velocity, water depth from the hydraulic modelling has been used for the determination of habitat suitability indices. The hydraulic modelling with HEC-RAS provided satisfactory results in our case.

4.2 HABITAT SUITABILITY CURVES

4.2.1 Marble Trout

The habitat suitability curves for two parameters depth and velocity for marble trout using the curves from(Vismara et al.) was calculated. The life stages juvenile and adults are also covered.

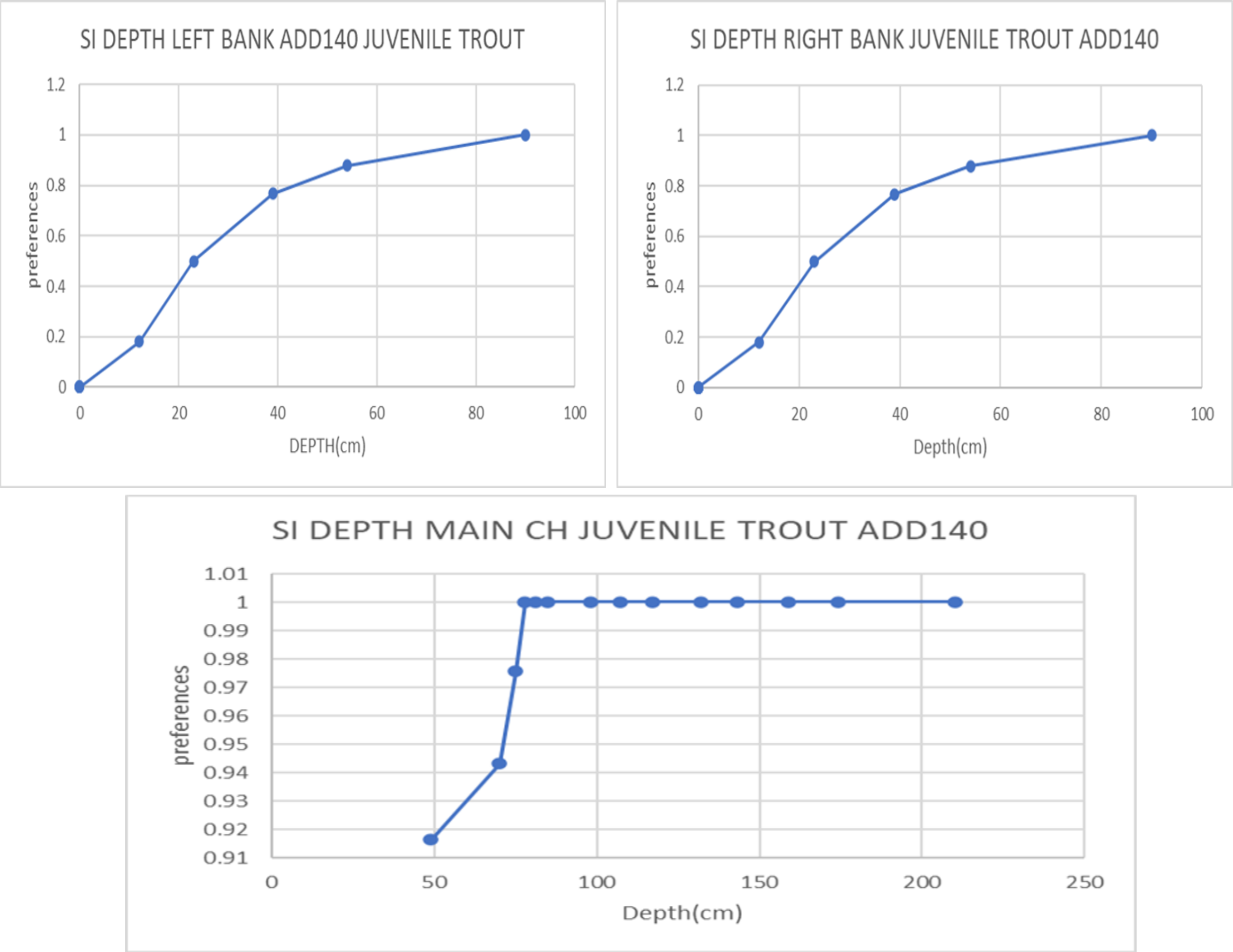


Fig 4.5 Depth Suitability Curves of Juvenile trout in left, right and Main channel of a section of Adda River

Similarly the velocity preference curve was also calculated. Fig 4.6 showing the velocity preference curve of juvenile marble trout in a particular section of Adda river .

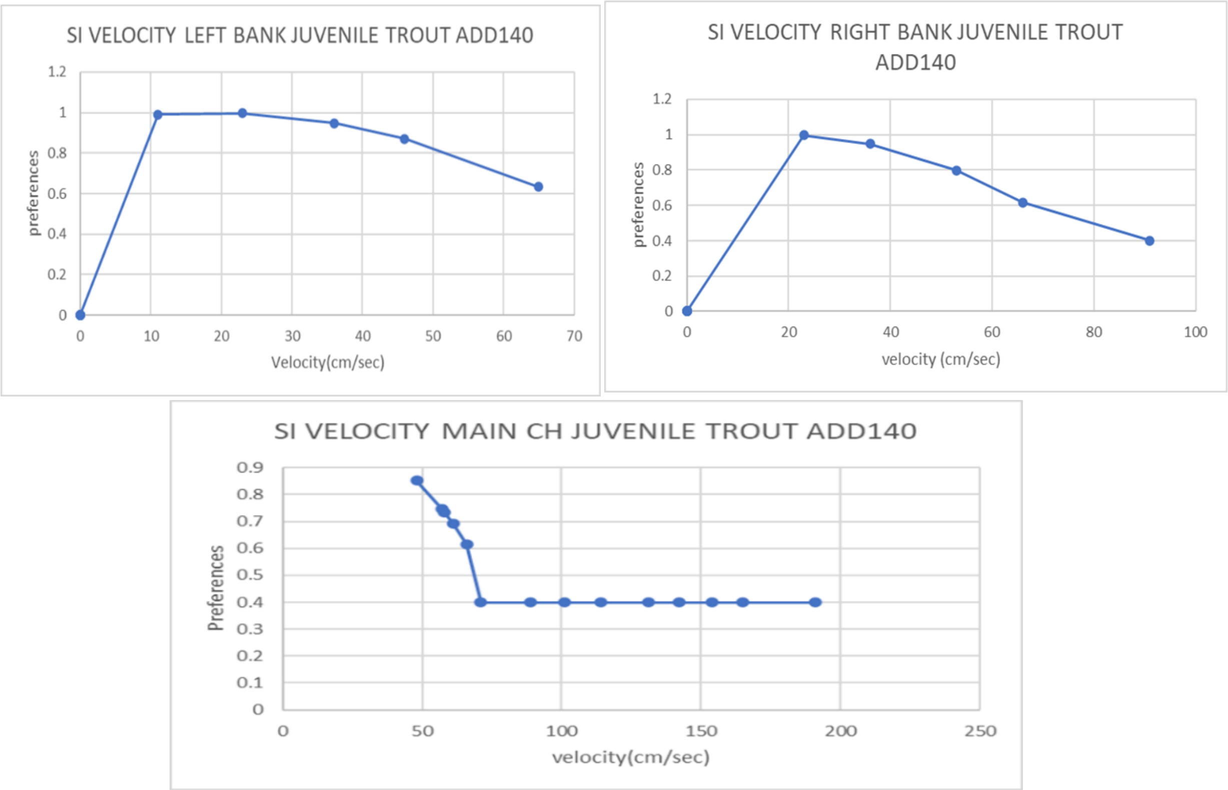


Fig 4.6 Velocity Suitability Curves of Juvenile trout in left, right and Main channel of a section of Adda River

We also calculated the Suitability duration curves to be familiar with the preference days of the species.

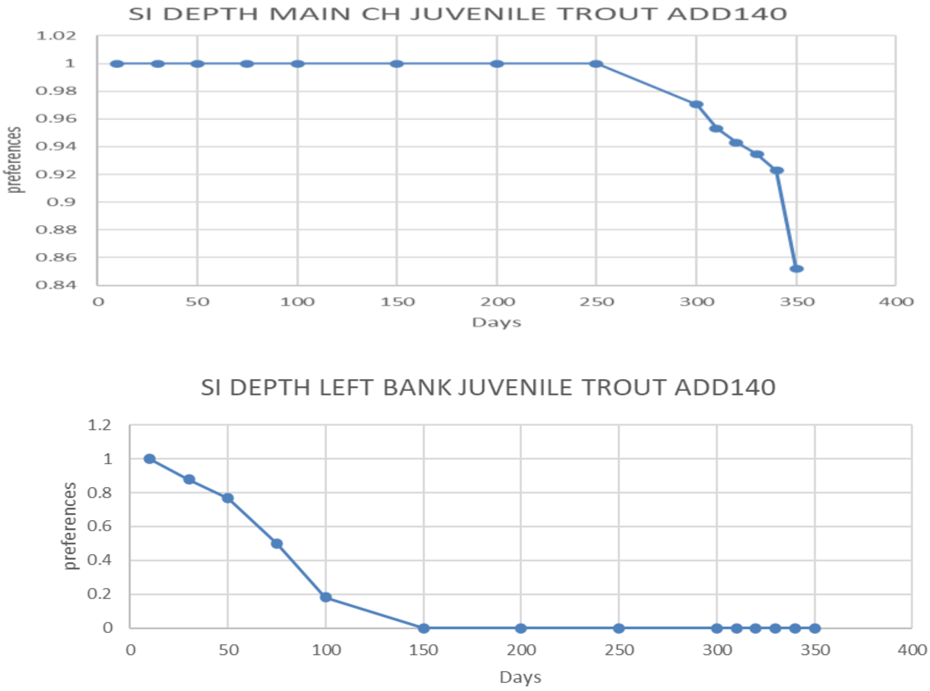


Fig 4.7 Depth Suitability Duration Curve of Juvenile trout in left and right banks of a section of Adda River

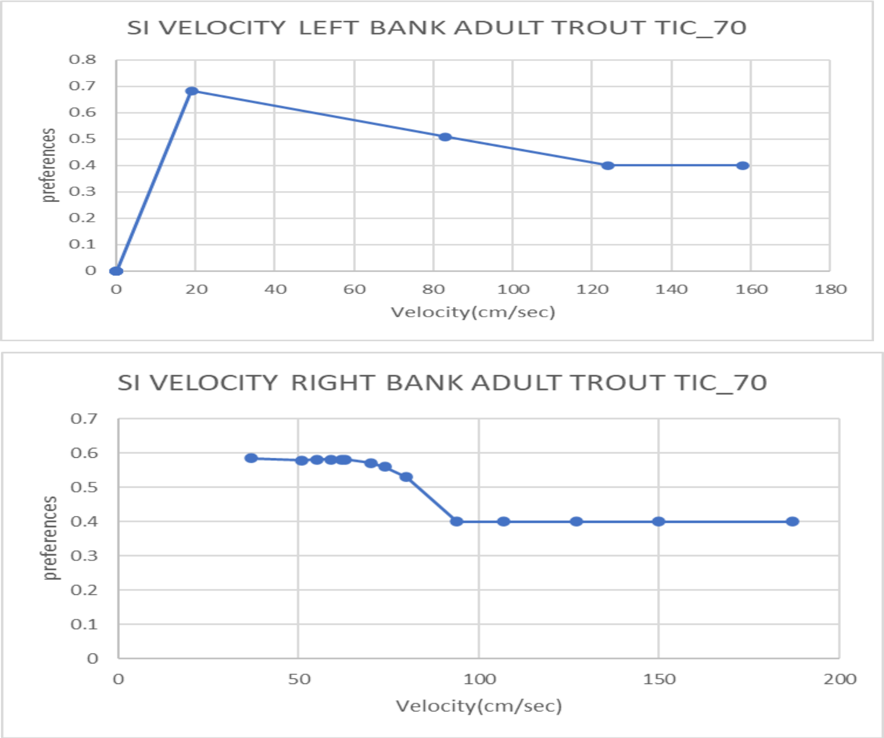


Fig 4.8 Velocity Suitability Curves of Adult trout in left, right Banks of a section of Ticino River

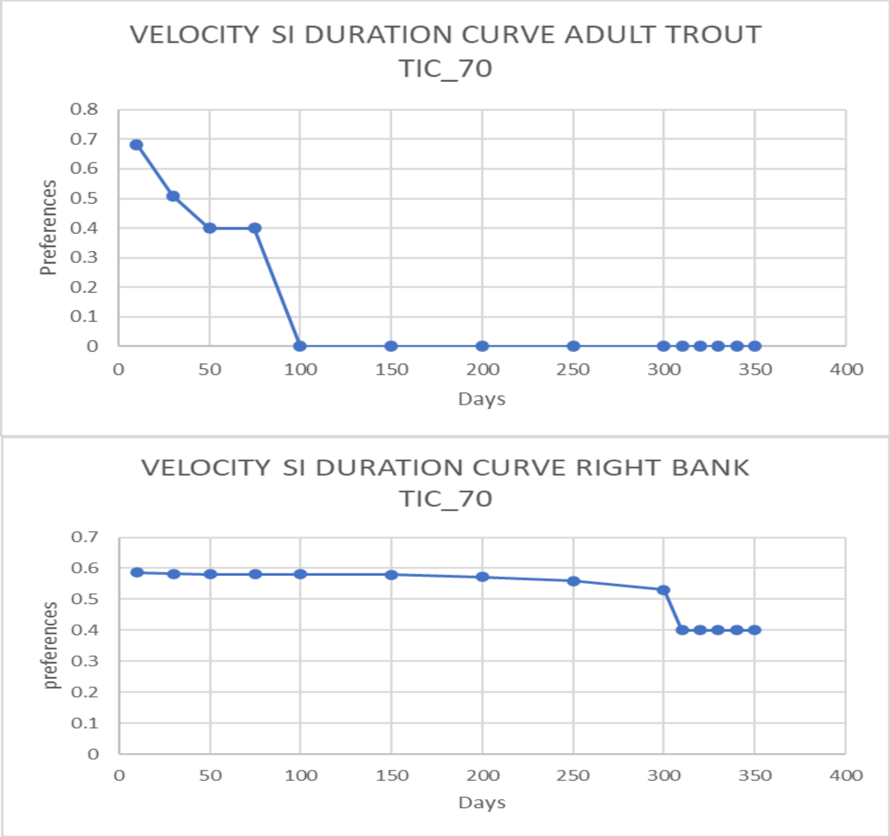


Fig 4.8 Velocity Duration Curves of Adult trout in left, right Banks of a section of Ticino River

4.2.2 BARBUS BARBUS (Italian Barbel)

The suitability curves for the barbus barbus calculated using the curves provided by(Rambaldi et al. 1997). The results of some particular sections of the both rivers are presented here.

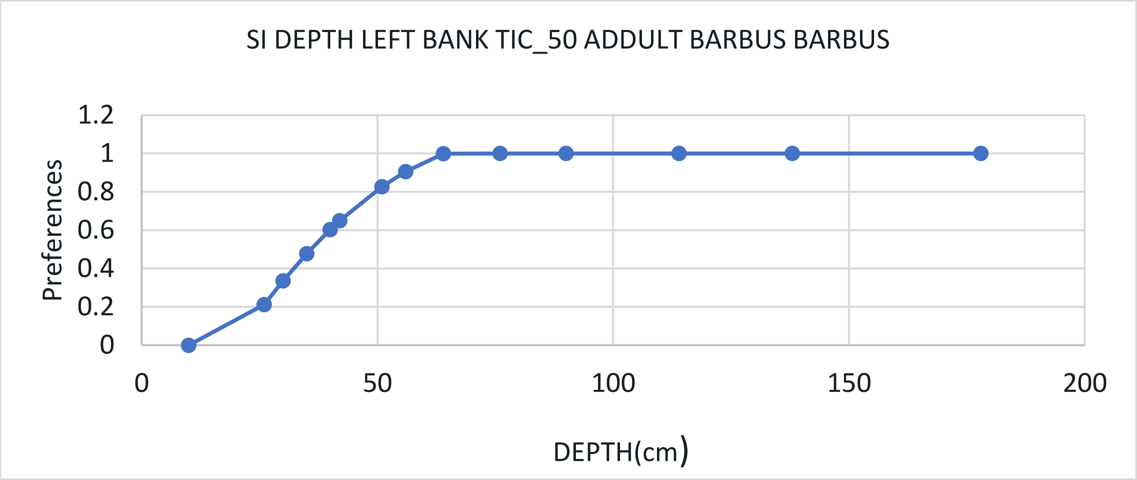


Fig 4.9 Depth Suitability Curves of Adult Barbus Barbus in left Bank of a section of Ticino river

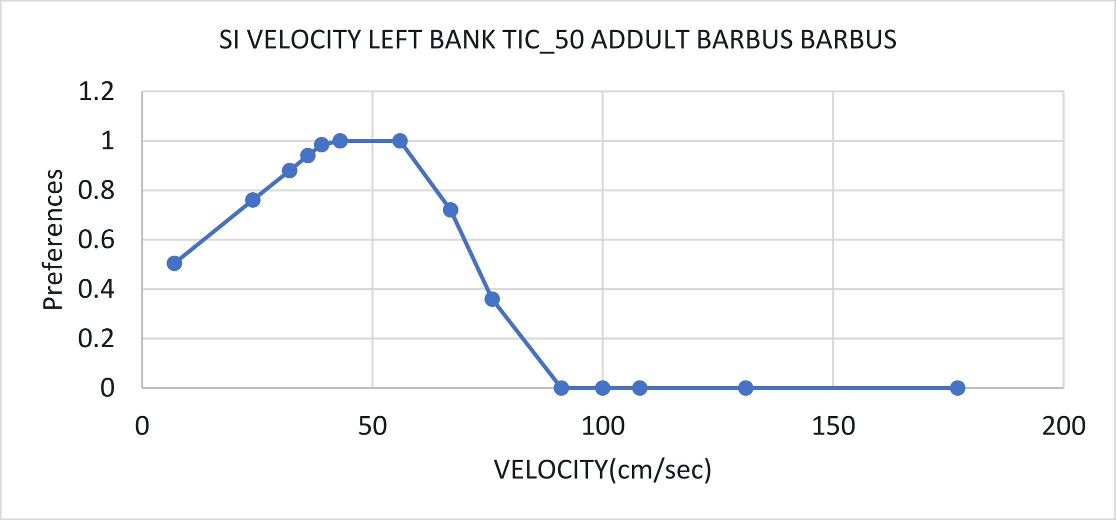


Fig 4.10 Velocity suitability Curve of Adult Barbus Barbus in left Bank of a section of Ticino River

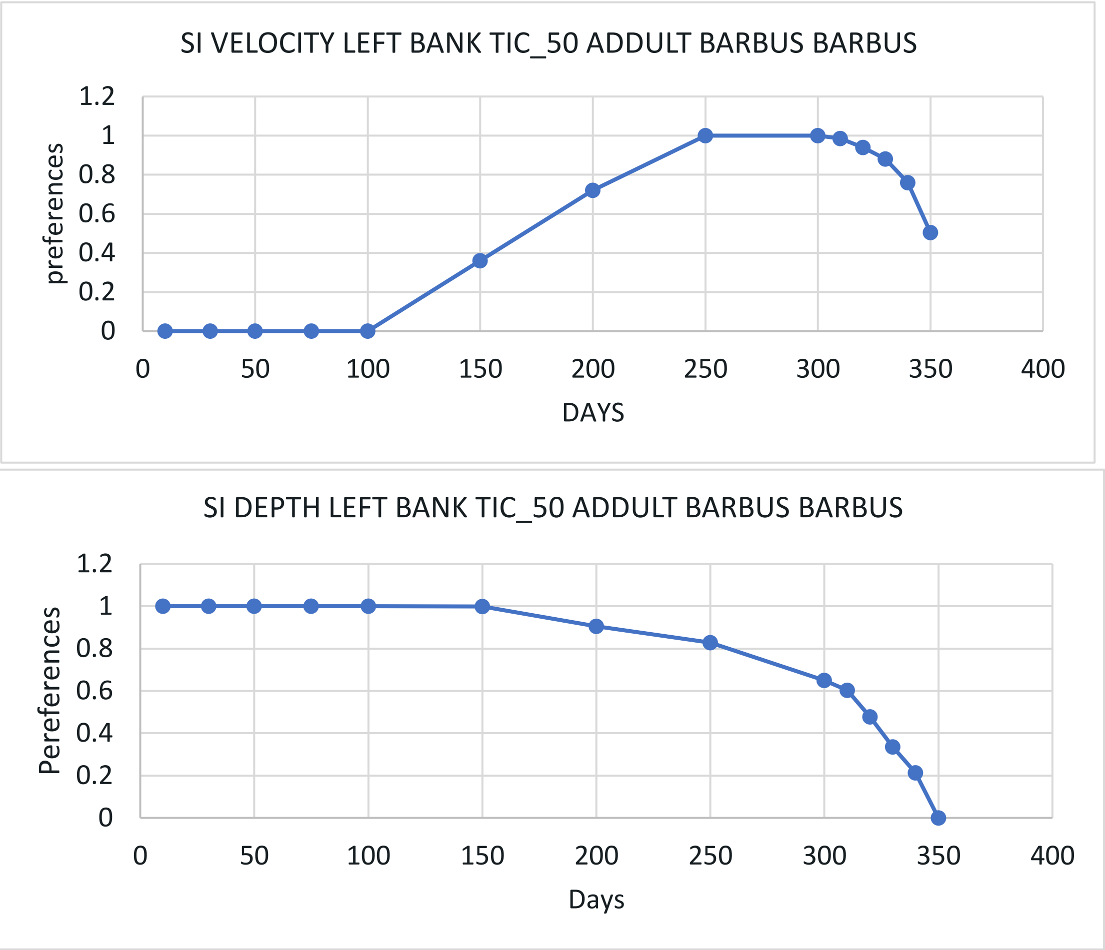


Fig 4.11 Velocity and Depth suitability Duration Curve of Adult Barbus Barbus in left Bank of a section of Ticino River

4.3 WEIGHTED USABLE AREA DURATION ASESSMENT

The weighted usable area duration curves has been calculated for both of the species. The results are presented in the form of maps for the whole length of the river. Here we just include representative low flow days maps of WUA duration curves. We also compared the flow area maps with weighted usable area duration curves maps.

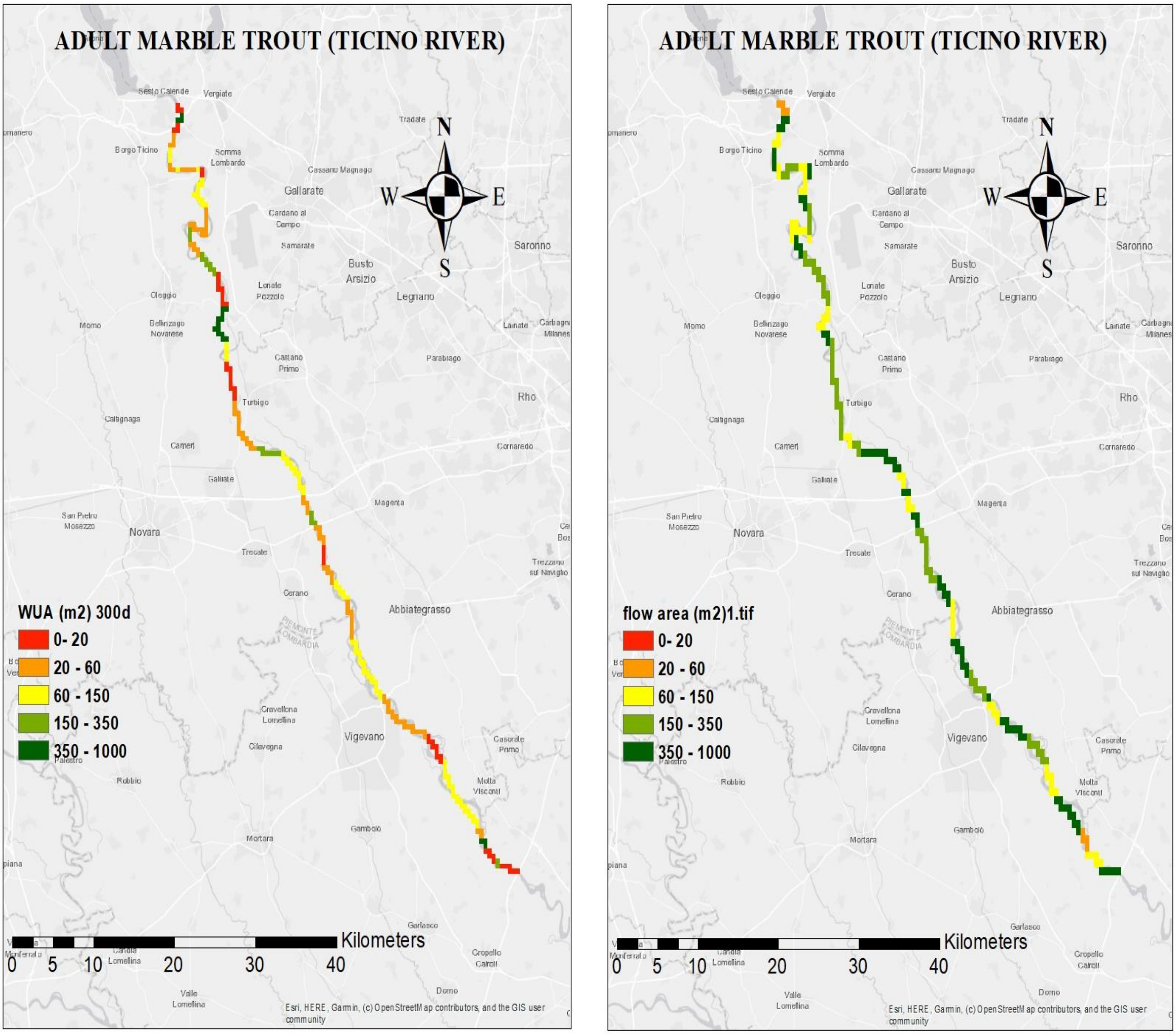


Fig . 4.12 maps showing the WUA and flow area

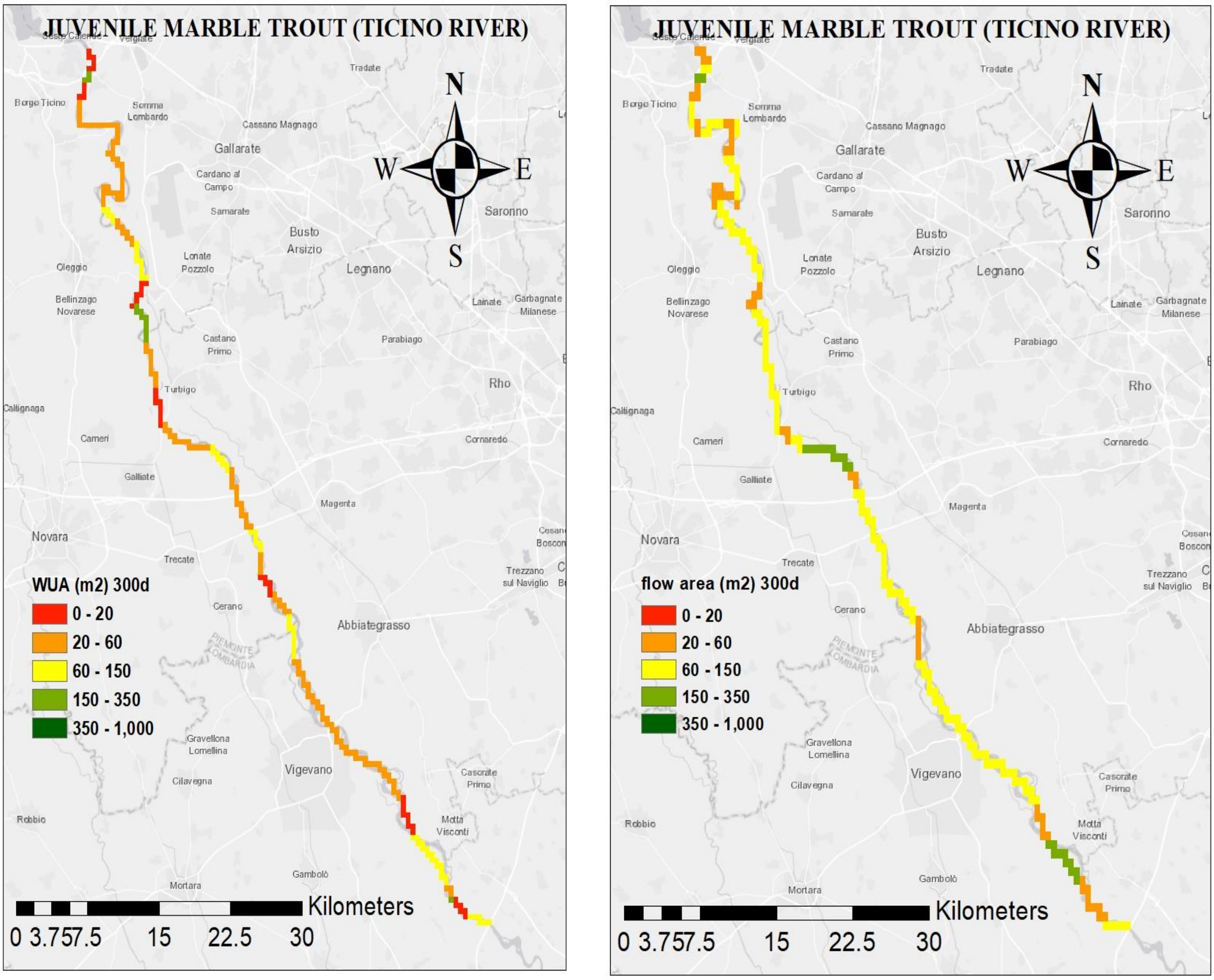


Fig . 4.13 maps showing the WUA and flow area

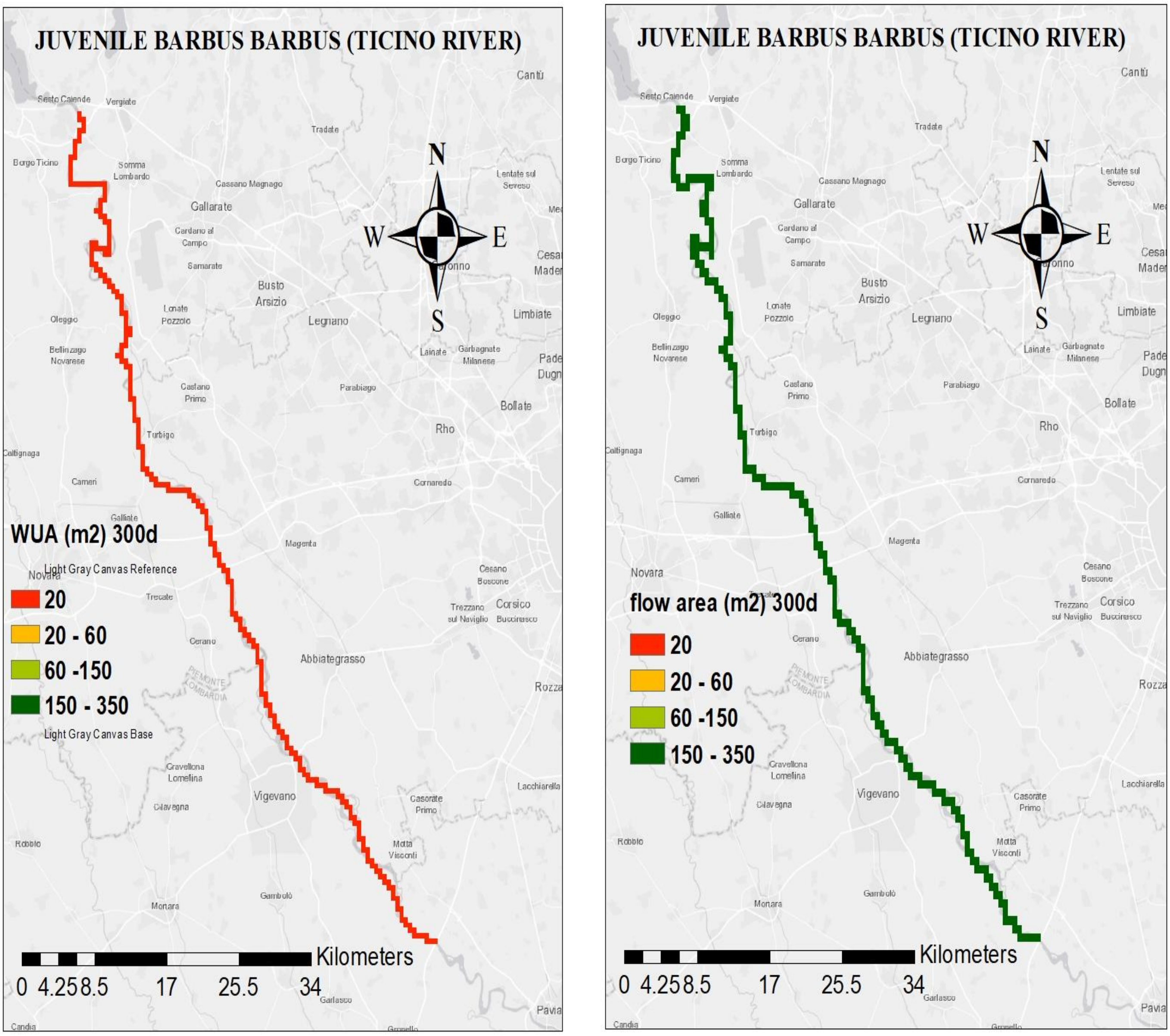


Fig . 4.14 maps showing the WUA and flow area

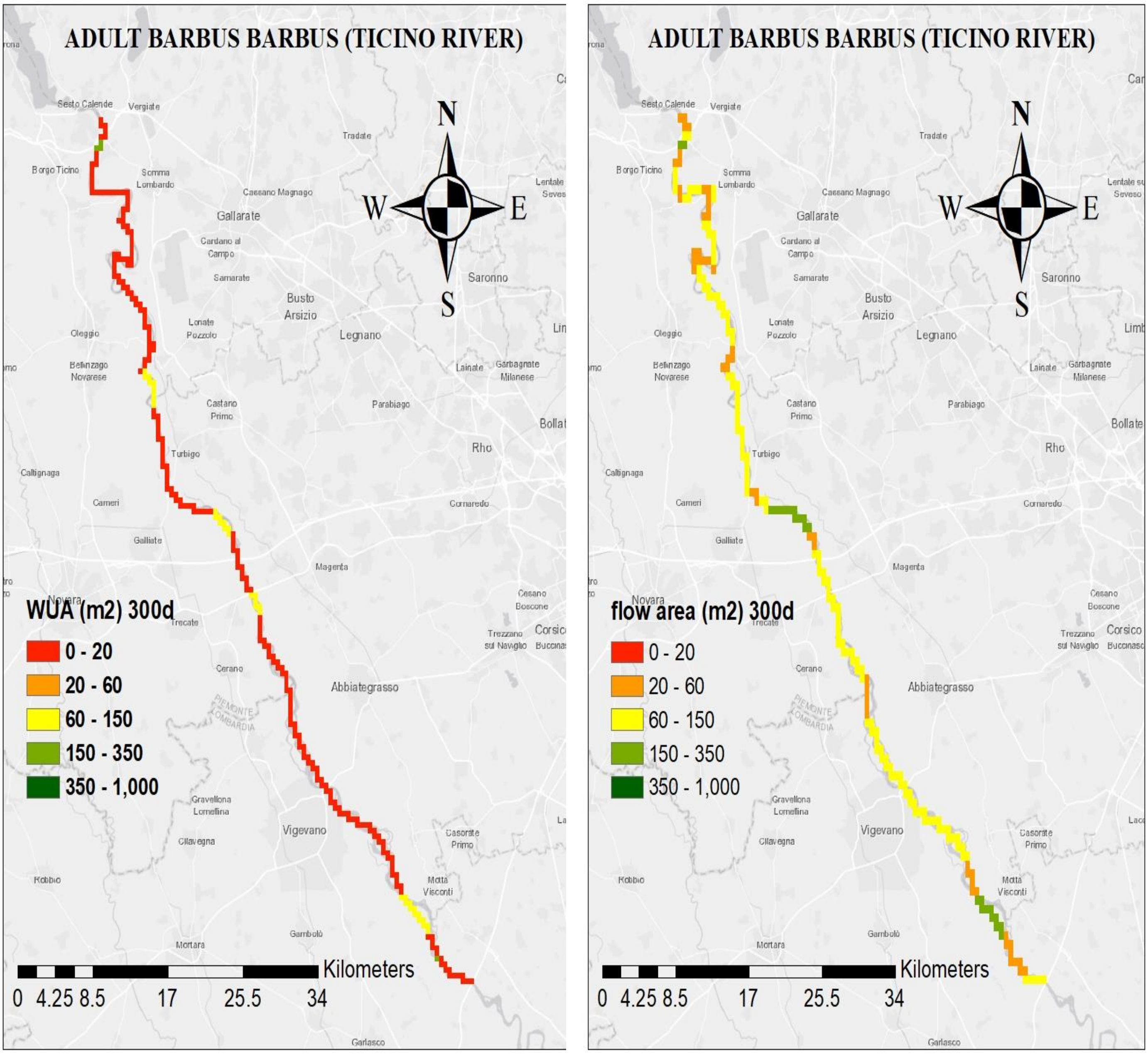


Fig . 4.15 maps showing the WUA and flow area

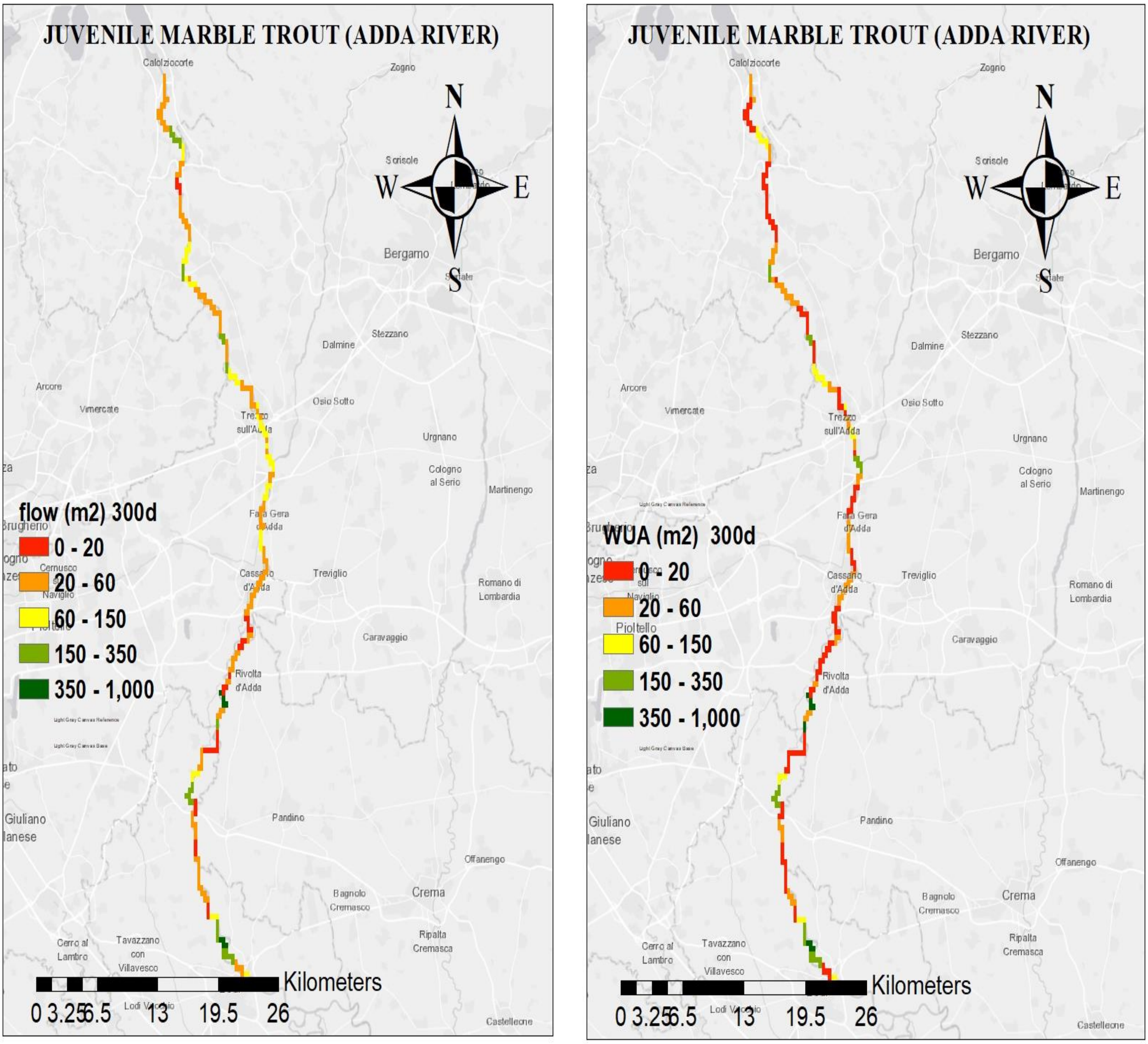


Fig . 4.16 maps showing the WUA and flow area

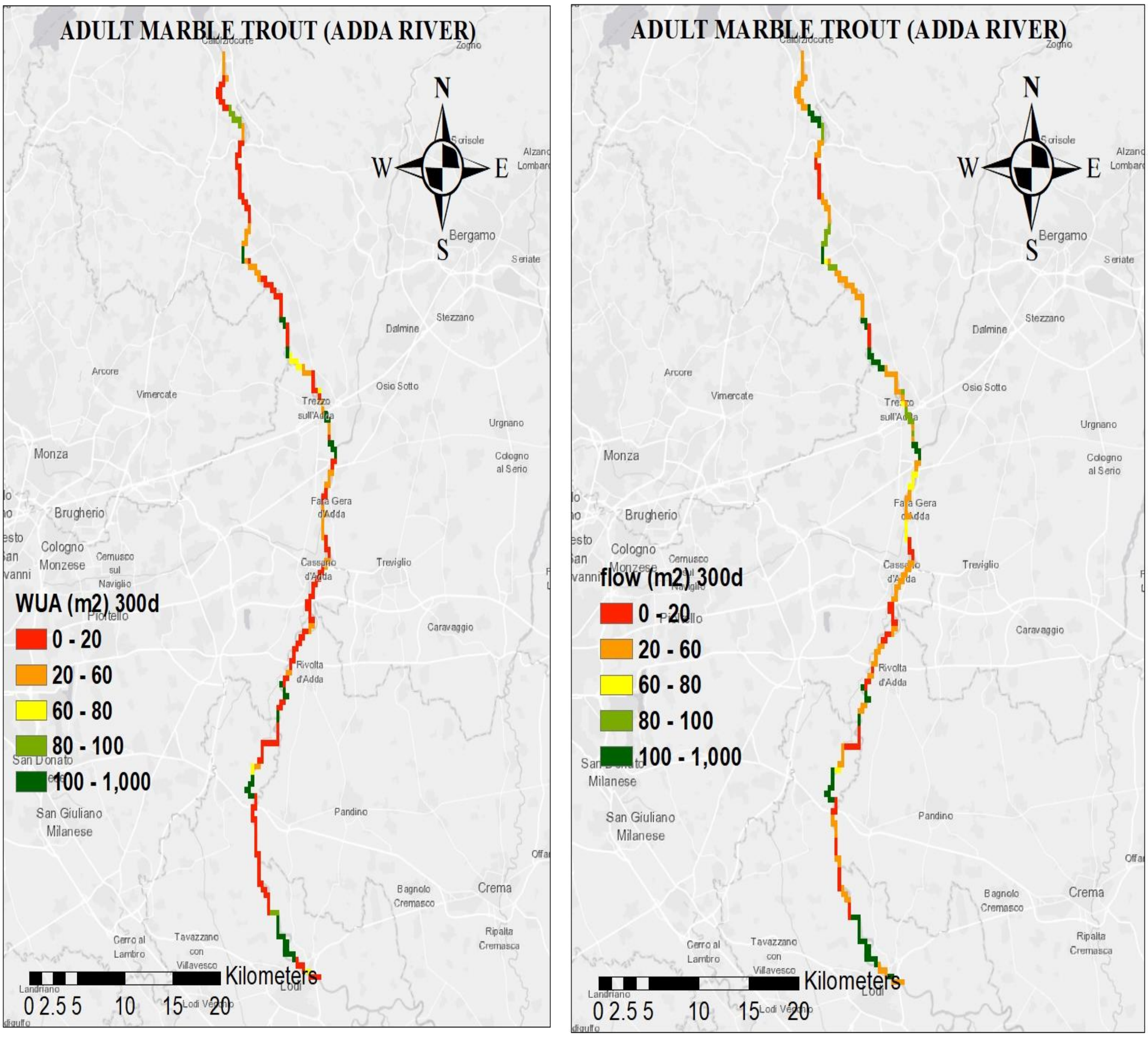


Fig . 4.17 maps showing the WUA and flow area

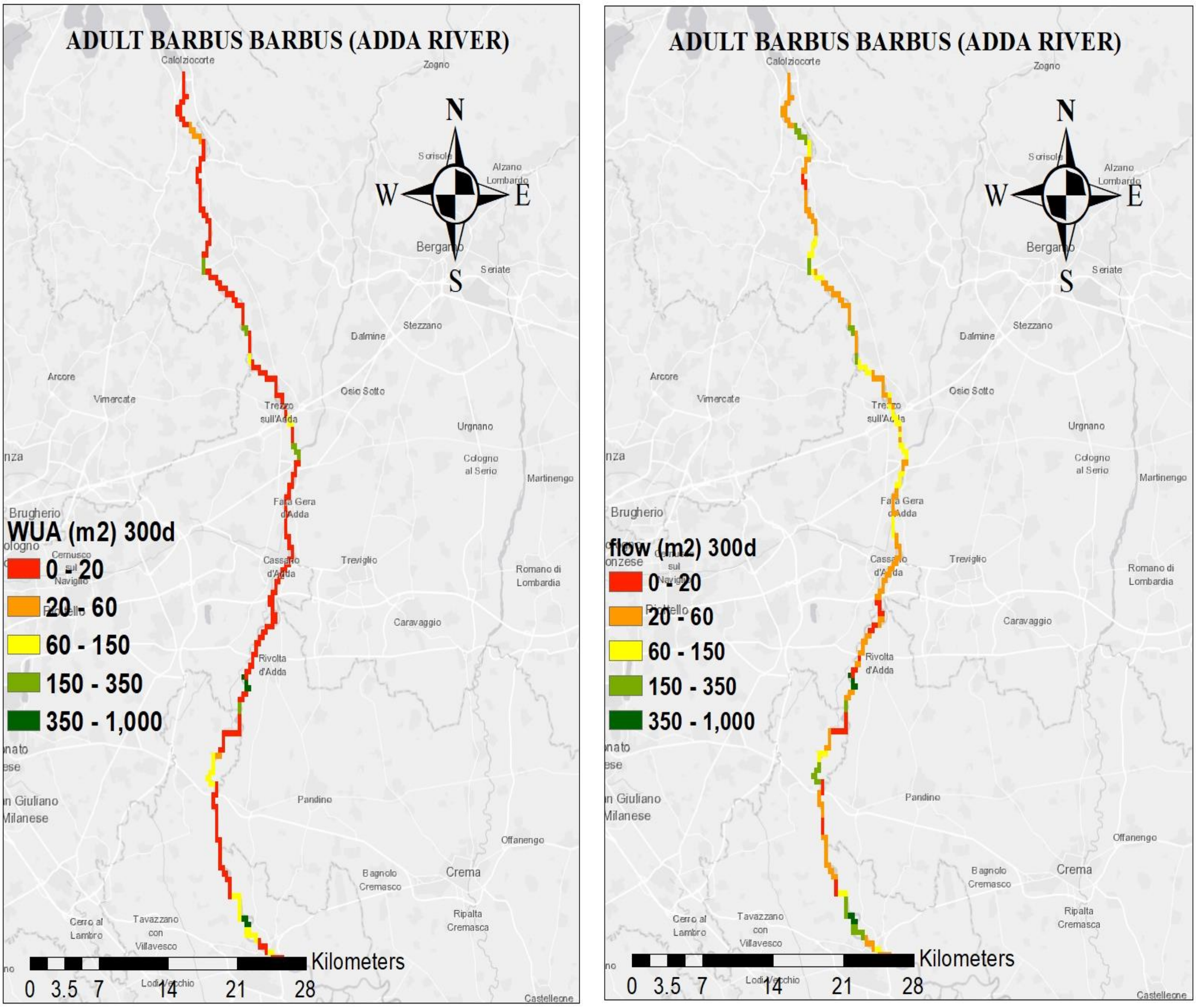


Fig . 4.18 maps showing the WUA and flow area

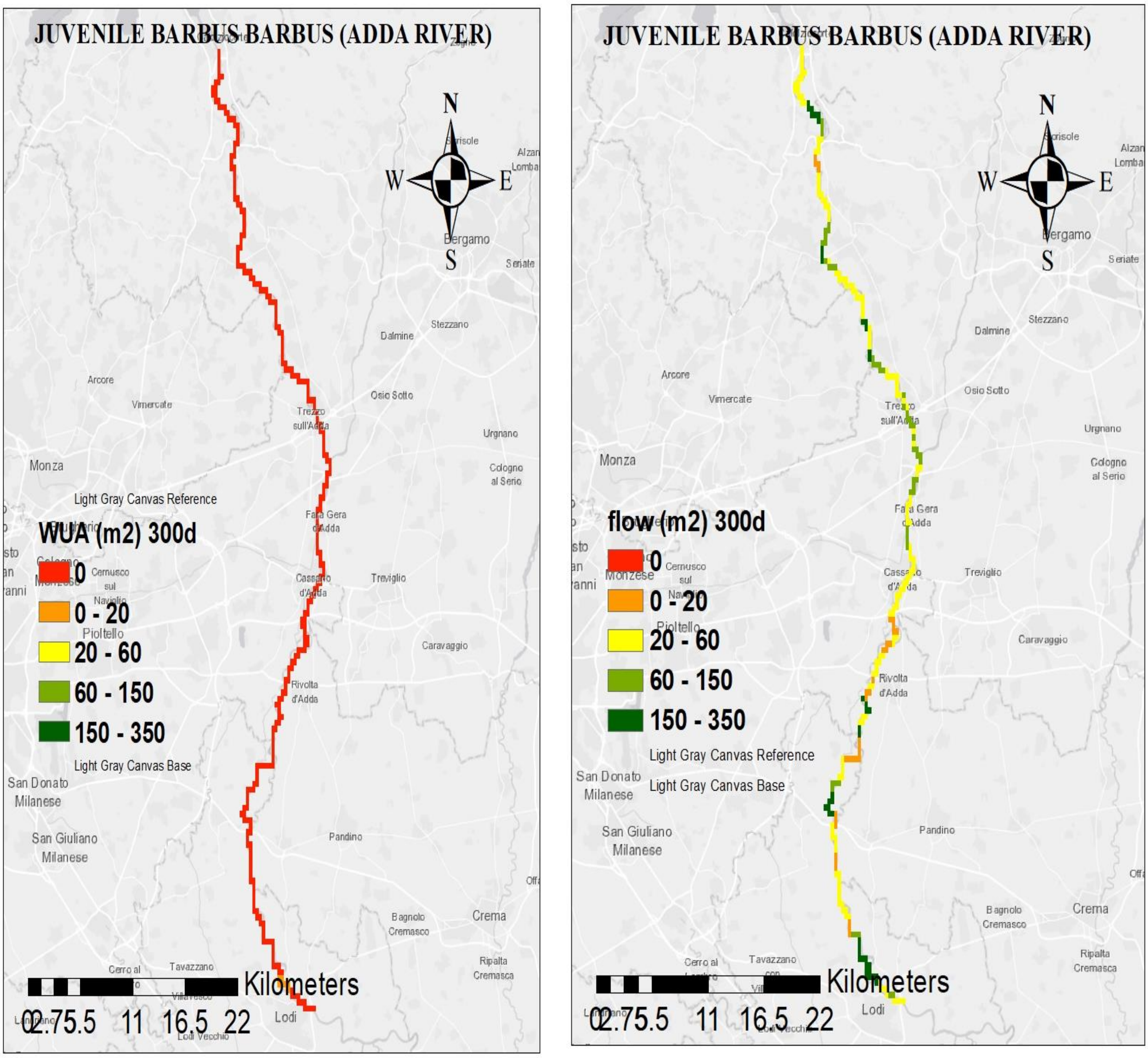


Fig . 4.19 maps showing the WUA and flow area

In order to understand the behaviour of WUA with discharge we plotted the average discharge and average WUA with respect to days for the all length of the study reach.

Fig. 4.20 Averaged Discharge and WUA duration Curve for Adult marble trout

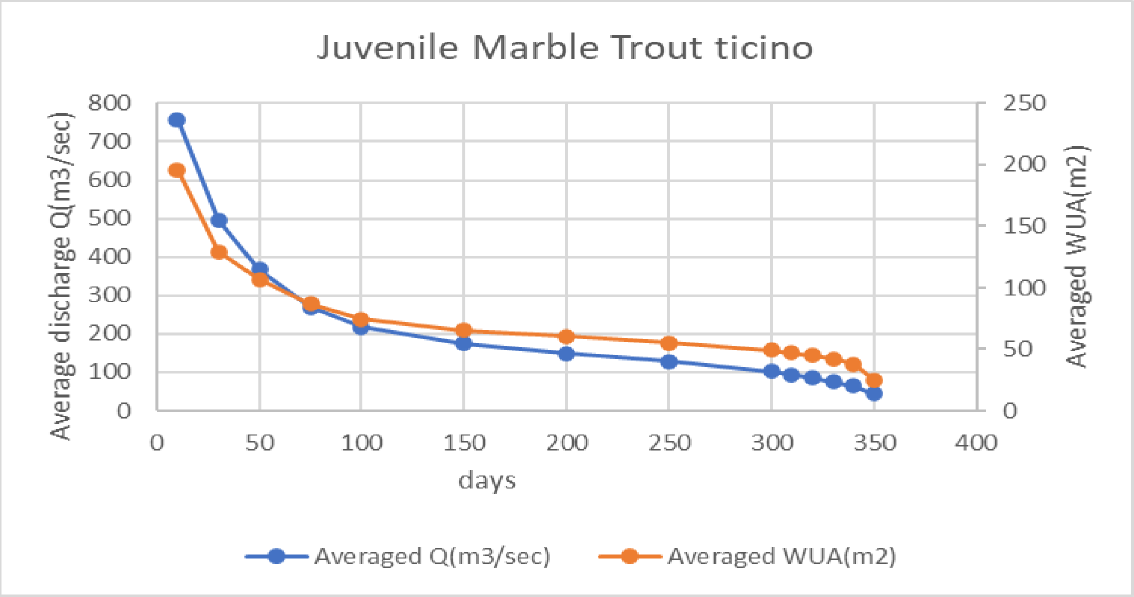


Fig. 4.21 Averaged Discharge and WUA duration Curve for Juvenile marble trout

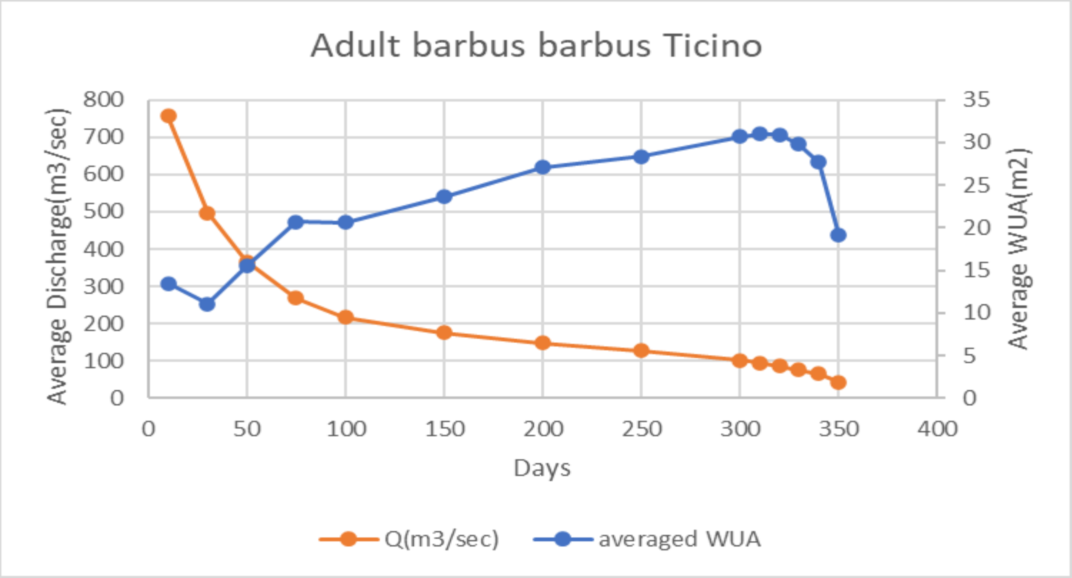


Fig. 4.22 Averaged Discharge and WUA duration Curve for Adult Barbus Barbus

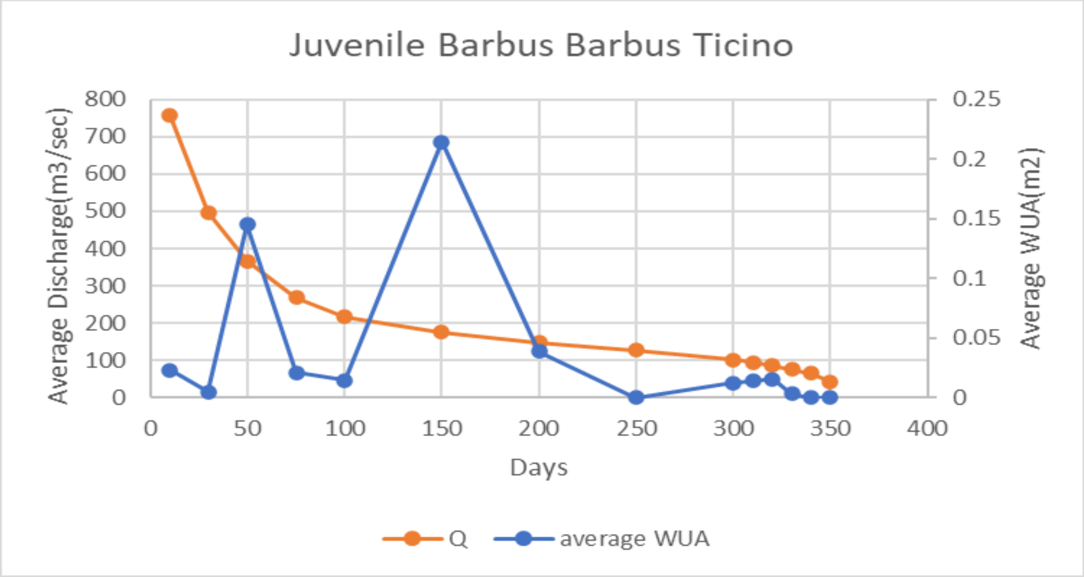


Fig. 4.23 Averaged Discharge and WUA duration Curve for Juvenile Barbus Barbus

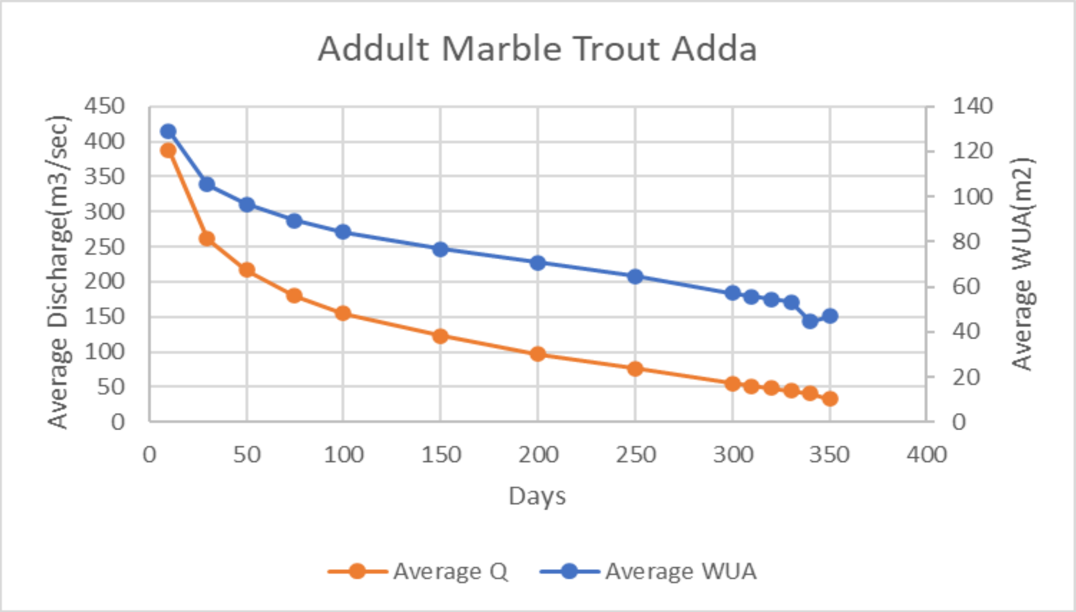


Fig. 4.24 Averaged Discharge and WUA duration Curve for Adult marble trout

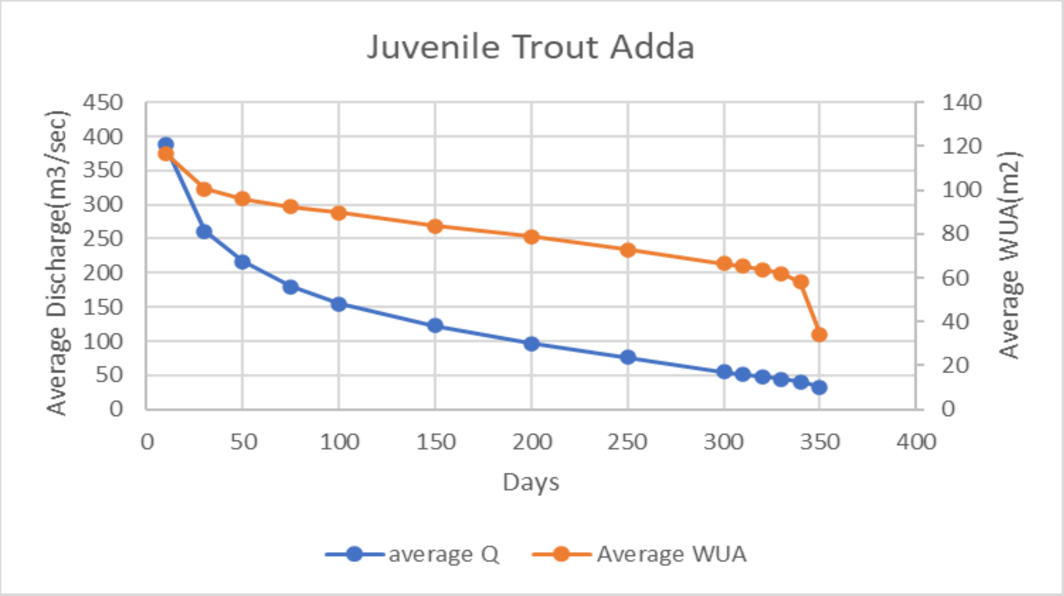


Fig. 4.25 Averaged Discharge and WUA duration Curve for Juvenile marble trout

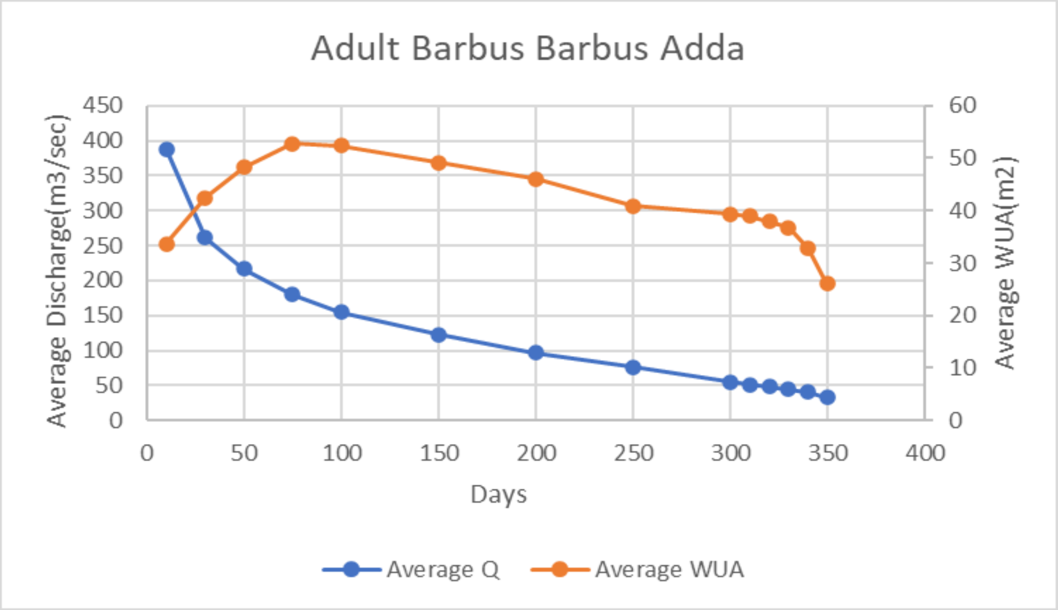


Fig. 4.26 Averaged Discharge and WUA duration Curve for Adult Barbus Barbus

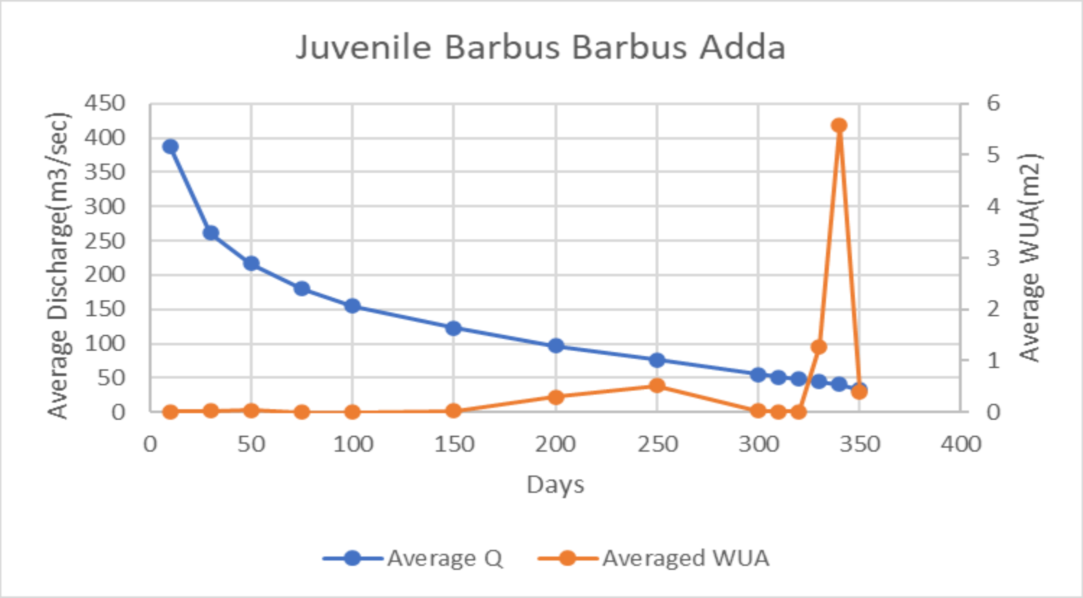


Fig. 4.27 Averaged Discharge and WUA duration Curve for Juvenile Barbus Barbus

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The HEC-RAS 1D model was capable of simulating the water surface levels for Ticino and Adda, the simulation results were technically sound and viable.We calibarated and validated the HEC-RAS model and the results were satisfactory.

The Results obtained by the application of Hydraulic- Habitat method on rivers Ticino and Adda shows that the Method provides reliable results.Regarding the targeted species for both life stage juvenile and adult the calculated WUA for low flow days shows that the for the barbus barbus most of the sections of both rivers are not suitable this was because the barbus prefer low velocities.

Analysing the WUA duration curves maps for the juvenile and adult trout for Ticino river its clear that the most of the sections of Ticino river are suitable for adult marble trout but for the juvenile trout the downstream sections looks not very suitable.

Furthermore the study can be carried considering the subtract index which we did not use in our study.it is recommended that if its possible the experimental suitability curves should be determined which will give a clear view of the minimum environmental flow situation. Environmental flow assessment approaches based on hydrology can provide basic estimates of environmental water demand at various scales. Implementing these methodologies are important as the first step toward environmental flow assessment in order to maximize the output of flowing water in rivers while preserving a healthier riverine ecology.

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