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ROCK RAMP IMPACT ON THE RIVERINE HYDRAULIC

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Abstract. *The following case study is part of a wider research of the impact of rock ramps on river environment. It aims to give a quantitative assessment of the velocity reduction in upstream section of a rock ramp. The alteration of the flow velocities is one of the most considerable factors for the habitat modification. The creation of still water environment in upstream impoundment might affect the physical properties of the habitat. Thus a mutation of the hydrobionts diversity may occur. By means of one – dimensional numerical model a comparative analysis of velocity fields is executed. Two cases are examined: before and after construction of a rock ramp with step – pools. The model proofs a significant flow velocity reduction in upstream section, which might have a negative environmental impact.Another point of interests of the study is the high flow river capacity. The flooded areas and the water level variation are evaluated at $Q_{50\%}$, $Q_{5\%}$ and $Q_{1\%}$. The results can be used for assessment of the structure reliability and for analysis of both: saturation of riparian zone and alteration of floodplain ecology.*

Key words*: Rock ramp, Water intake, River environment, Numerical modelling*

1. INTRODUCTION

The fragmentation of the longitudinal river corridor by weirs, dams, hydropower facilities and culverts represents a major global human impact on running waters (Broadhurst et al., 2012, Stoller et al., 2016). While the obvious and often irreversible impacts of large impoundments are now well recognized, there is also growing awareness of the pivotal role of the flow regime as a key ‘driver’ of the river ecology and their associated floodplain (Baki et al., 2014, 2015, 2016).

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The impact from alterations to natural hydrology, changes to stream geomorphology, disruption of localised erosion and sedimentation processes, evaporative water loss, creation of still water environments, impediment of larval drift and extractive water use have had a severe negative impact on the abundance and diversity of native fish populations and the quality of aquatic habitats throughout the world (Ghimire and Jones, 2014, Cassan and Laurens, 2016).

Many fish species display a preference for particular types of habitat such as pools, riffles or backwater areas (Matthews, 1985, Angermeier, 1987, Pusey et al., 1993). The richness of the fauna often increases as habitat complexity increases, with depth, velocity and cover being the most important variables governing this relationship (Gorman and Karr, 1978, Felley and Felley, 1987, Pusey et al., 1995).

The Marica River is located in South Bulgaria and is a part of the European network Natura 2000 for protection of the habitats. In some areas, it is included in the network for protection of the birds. Its waters are used intensively for public water supply, irrigation and industry.

In the last decades, as a result of the increased anthropogenic impact in the river basin, considerable river bed degradation has been observed. In certain areas, there is coastal erosion that puts at risk a number of facilities and farmlands. The main reasons for this negative trend are sand and gravel extraction, river modification, and disturbed sediment balance in the river basin.

As a consequence of the above mentioned problems, water level decreases constantly and many of the water intake structures are left above the water level. The challenge is to find an engineering solution, which will stabilize the river bed and increase the water level, without considerable fragmentation of the river ecosystem.

2. DESCRIPTION OF THE FACILITY

The Marica River is the largest river in Bulgaria with a catchment area about 53 000 km^2 (Fig. 1). It rises from Marichini lakes in Rila mountain. Its mean annual flow varies from 0.628 m^3/s at altitude of 1900 m to 107.92 m^3/s at the border between Bulgaria and Turkey.

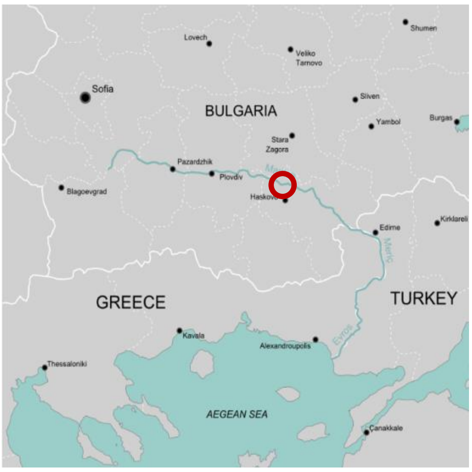

Fig. 1 Location of the Marica River and the examined section

The examined section of the Marica River is a part of the European ecological network Natura 2000 for the habitats and birds protection, which presumes significant requirements for design and construction of weirs or dams in the Management Plan of the River basin. The midstream represents a modified river section for protection of harmful effects of water. During the last decades, due to the active anthropogenic impact considerable erosion process occurred (Fig. 2).

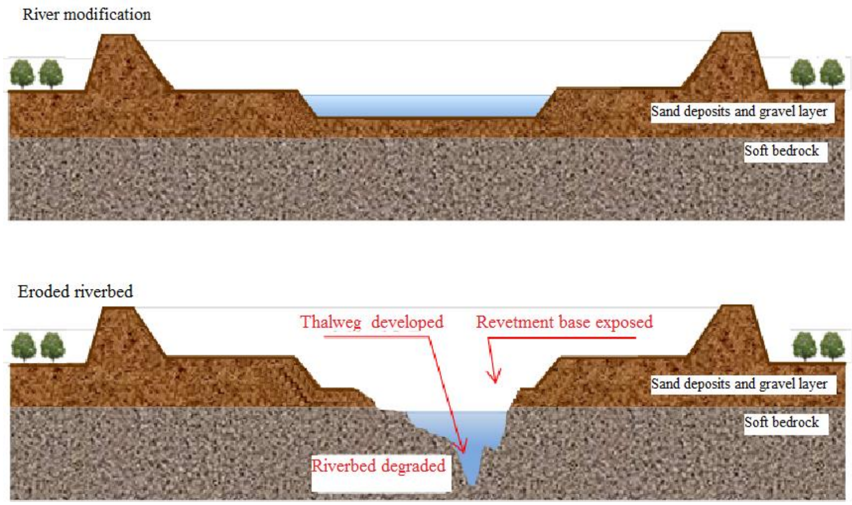

Fig. 2 River bed degradation

A scenario with rock ramp construction is investigated, as an erosion control structure with a low ecological impact. There are different types of block ramps: on the one hand the block ramps formed by a block carpet, where the entire flume width is covered by blocks, and on the other hand the block ramps formed by different configuration of clusters (Fig. 3). Each ramp type establishes different hydraulic conditions and thus needs to be investigated separately (Tamagni, 2013).

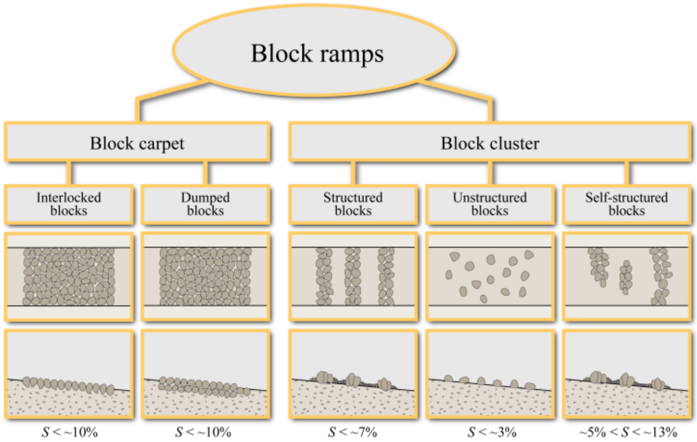

Fig. 3 Classification of block ramps (Tamagni, 2013)

The proposed facility (step – pool rock ramp) aims to increase the water level, providing water discharge for the diversion canal, and to limit the erosion process in the river bed (Fig. 4). At the same time it offers an opportunity for migration of different fish species at different water discharges.

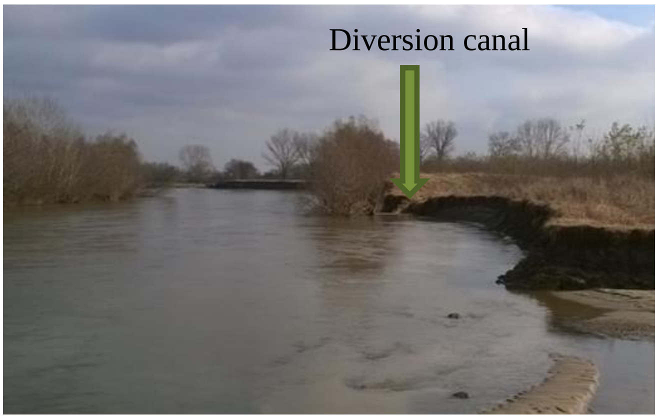

Fig. 4 River bed erosion and collapsed water intake

The rock ramp (Fig. 5) consists of a low-flow channel designed to maintain biologically adequate depth and velocity conditions for upstream and downstream migration during periods of small discharges (Studer and Schleiss, 2009, 2011). Under low-flow conditions, downstream sections are unlikely to influence flow depths on the ramp. Therefore, hydraulics could be determined using normal depth calculations which provide a quick determination of the low-flow channel width and ramp length meeting low-flow fish passage depth and velocity conditions (Mooney, 2007).

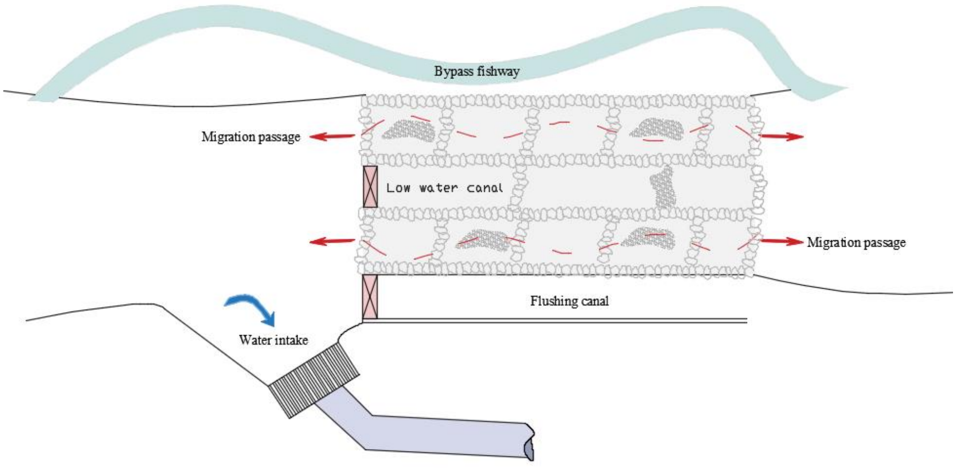

Fig. 5 Plan of a water intake with rock ramp

In the zone of the water intake is located the flushing channel for the deposited sediments. Its additional purpose is to release part of the high flow discharges.

The fish migration might occur through the bypass fish way or through the rock ramp body. The position and the size of the step – pools are from great importance. There are various configurations and arrangements of rock that can be utilized provided the rock is large enough to be essentially immobile and the drops are low enough to allow aquatic life to migrate upstream (Tamagni et al., 2010). The variety of flow conditions in the step – pools is an important issue, which solution could be proofed by 3D model.

Within the framework of this study is examined a solution with the construction of a rock ramp (2.4 m high, 1:30 longitudinal slope). The effects of this measurement should be stabilization of the river bed, groundwater accumulation, as well as water supply for wetlands and floodplains due to rising water levels. Access to the flood plains is essential to the reproduction of numerous species that spawn in such habitats when food resources are abundant. Effective management of floodplain barriers is required to ensure that ecological functioning is maintained. The proposed concept aims to ensure a water discharge for the intake structures under the following conditions:

- flow characteristics and dynamics preservation,
- preservation of river continuum,
- reliable erosion protection,
- high water flow conveying.

Qualitative assessment of the flow characteristic and dynamic preservation rate could be given after comparative analysis of the velocity fields for both cases: before and after the rock ramp construction. The rivers in their upper and middle streams are composed of small sections (meso-scale habitats) with different physical characteristics (rapids, still water etc.), which represent a wide range of microhabitat variables as water depth, flow velocity, substrate, and shading. Usually, if a weir is constructed the upstream zone gets more homogenous, the flow velocity decreases significantly, the water depth increases and substrate gets more monotonous. In many cases that causes a considerable habitat modification, which leads to distribution shifts of the typical fish species, macrozoobenthos and macrophytes to fatally block or delay upstream fish migration.

The water continuum preservation is a very complicated issue, because it requires a complex evaluation. On one hand the river ecosystem fragmentation causes disturbance of the migration of species, which depend on longitudinal movements along the stream continuum during certain phases of their life cycle. This requires detailed information for the hydrobionts, their migration behaviour and capacity. On the other hand the disturbance of the sediment balance and the nutrient distribution as a consequence of the weir or dam construction might lead to upstream habitat modification and to downstream erosion processes and nutrient demand.

3. NUMERICAL MODEL

The main abiotic factors that have an impact on the specifics of the flow and thus on the physical characteristics of the habitats are: flow velocity, water depth and water level variation.

The two basic purposes of the modelling procedure are to determine the flow velocity alteration in the upstream river section as a consequence of the rock ramp construction and to verify the river capacity during peak water discharge.

3.1. Description of the model

The study is conducted using a numerical 1D model HEC – RAS (Hydrologic Engineering Center - River Analysis System) version 5.0, developed by the U.S. Army Corps of Engineers. The HEC – RAS system contains the following river analysis components for: (1) steady flow water surface profile computations; (2) one-dimensional and/or two-dimensional unsteady flow simulation; (3) quasi unsteady or fully unsteady flow movable boundary sediment transport computations; and (4) water quality analysis. The component for steady flow, which is used in this case, is intended for calculating water surface profiles for steady gradually varied flow, where the following flow condition is assumed (Brunner, 2016):

- steady flow,
- hydrostatic pressure distribution,
- velocity vector is in flow direction only,
- no channel geometry alteration in time.

The basic computational procedure is based on the solution of the one dimensional energy equation (Bernoulli equation) by means of the standard step method. The energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change of velocity head).

For this case study purposes a georeferencing model with 111 profiles was created, which covered more than 6000 m long river section. The profiles and the areas with different Manning coefficient were defined (Richardson et al., 2001, Rice et al., 1998) in ArcMap 10.4. Two scenarios were considered – before and after construction. The calculations were performed for water discharges with the following probabilities: 1%; 5%; 25%; 50%; 75%; 95%;

3.2. Results

3.2.1. Velocity field's alteration

It is obvious from the results that the velocity variation curves follow the same trends in both cases: before and after construction (Fig. 6). The difference between the values varies from 30% to 60% in some sections. As it was expected, the zone with the lowest velocities is in the area before the rock ramp, where the differences in values are the highest. The final assessment, how the flow velocity reduction and the increased water depth will modify the habitats, must be given after detailed analysis of their physical properties and the behaviour of the hydrobionts, which is not part of this study.

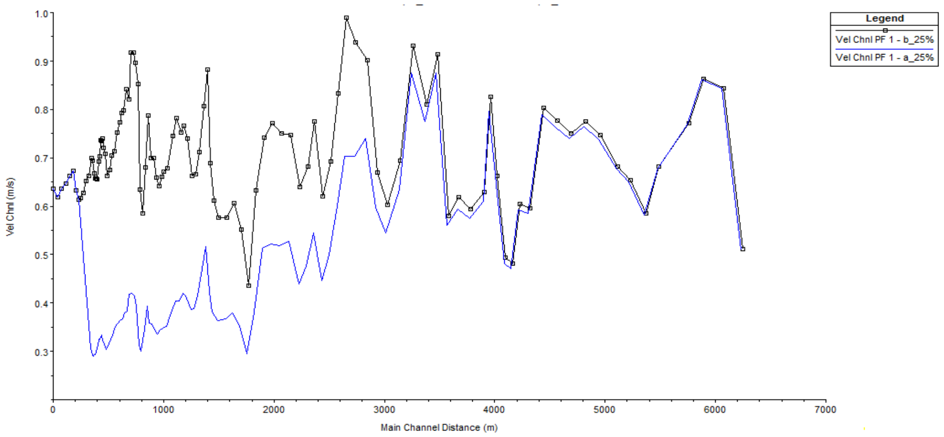

Fig. 6A Flow velocity curves before and after construction for $Q_{25\%}$

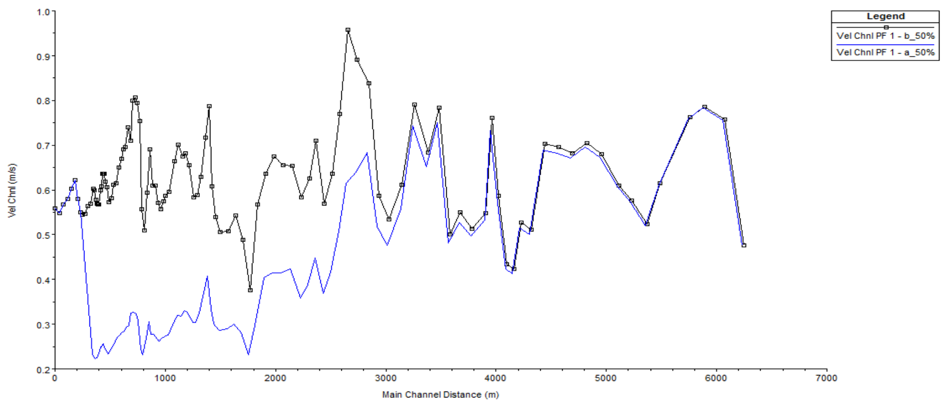

Fig. 6B Flow velocity curves before and after construction for $Q_{50\%}$

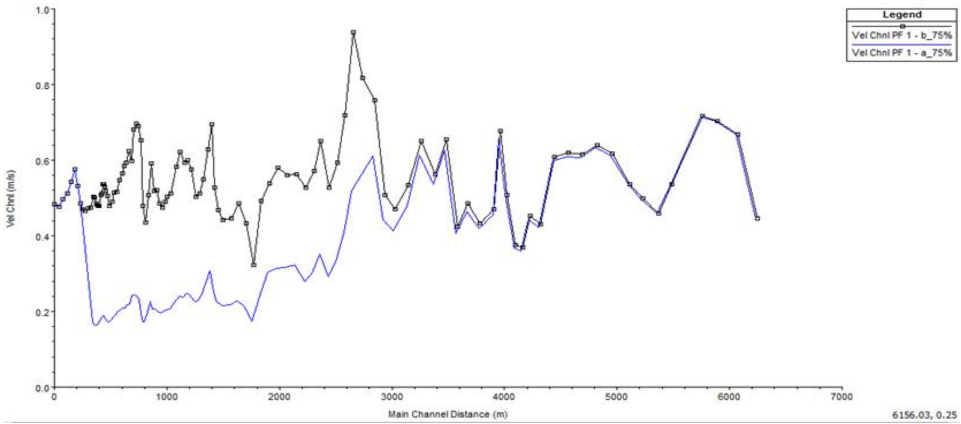

Fig. 6C Flow velocity curves before and after construction for $Q_{75\%}$

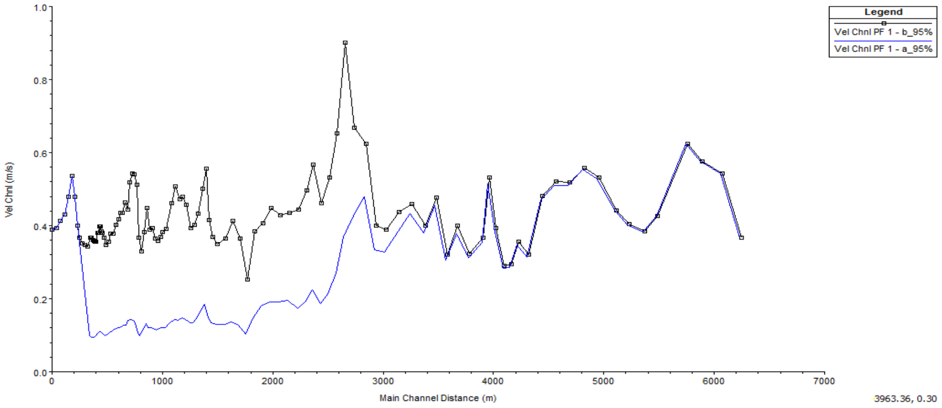

Fig. 6D Flow velocity curves before and after construction for $Q_{95\%}$

3.2.2. High flow river capacity

The structure reliability analysis is performed for water discharges $Q_{1\%}$ and $Q_{5\%}$, according to the Bulgarian legislation. The results indicate an insignificant flow modification caused by the rock ramp construction. The reason could be explained with the shape of the river bed cross section, which could be interpreted as a compound trapezoid. With higher water discharge than $Q_{5\%}$ the rock ramp is fully submerged and water level reaches the levees toe. This can be seen from the rating curves comparison (Fig. 7) and from the flooded areas map (Fig. 8). With water discharge $Q_{1\%}$ flow over the levees crown is not to be expected.

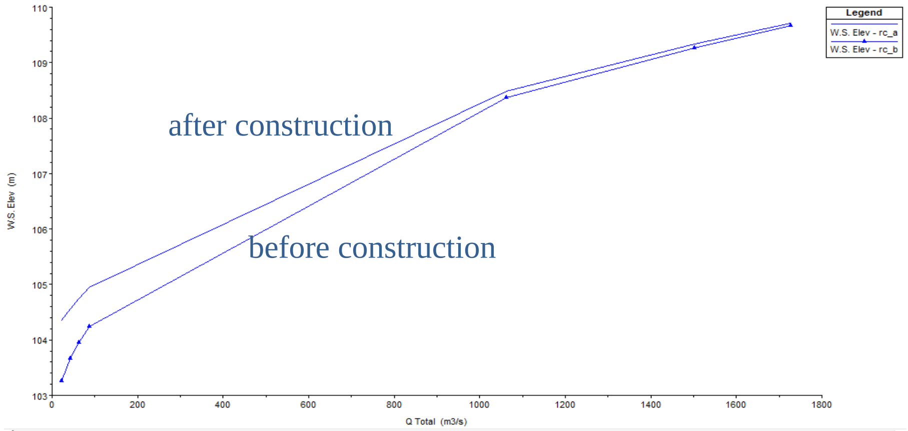

Fig. 7 Rating curves before and after construction

Fig. 8A Flooded areas at $Q_{50\%}$

Fig. 8B Flooded areas at $Q_{5\%}$

Fig. 8C Flooded areas at $Q_{1\%}$

4. CONCLUSIONS

The flow velocity alteration in upstream section of weir or dam is an important prerequisite for analysis of the river ecosystem modification. The excessive decrease might lead to changing of the physical, chemical and biological properties of the habitat.

The designed rock ramp causes a significant velocity reduction in upstream section, in some areas with more than 50%. The velocity curve profile gets flatter after the facility construction, which means reduction of the flow patterns diversity. It is important to note, however that one – dimensional modelling estimates mean values of velocities in every cross section, which might be an effective starting point for further investigations. Flow variety might be examined more precisely by means of more dimensional models.

With regard to the high water conveying, an insignificant water level increase by reason of the rock ramp construction is observed. At $Q_{50\%}$ the Northeast bank gets partly submerged, due to its flatter topography. The influence of the rock ramp on the water level decreases with increasing the flow discharge.

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UTICAJ KAMENE RAMPE NA HIDRAULIKU REKE

Studija slučaja prikazana u ovom radu je deo šireg istraživanja o uticaju kamenih rampi na životnu sredinu reke. Ona ima za cilj da da kvantitativnu procenu smanjenja brzine u uzvodnoj deonici kamene rampe. Promena brzine toka je jedan od najznačajnijih faktora za modifikaciju staništa. Formiranje mirne vodene sredine u uzvodnom usporu može uticati na fizička svojstva staništa. Tako može doći do promene biodiverziteta organizama koji žive u vodenoj sredini. Primenom jednodimenzionalnog numeričkog modela izvršena je komparativna analiza polja brzina u zoni kamene rampe. Ispitana su dva slučaja: pre i posle izgradnje kamene rampe sa stepenik – bazen strukturom. Model dokazuje značajnost smanjenja brzine toka vode u uzvodnoj deonici, što može imati negativan uticaj na životnu sredinu.Još jedan aspekt interesovanja ove studije je kapacitet reke sa kamenom rampom za prijem velikih voda. Poplavljena područja i varijacije nivoa vode su procenjeni za proticaje Q50%, Q5% i Q1%. Rezultati mogu da se koriste za procenu pouzdanosti strukture i za analizu kako zasićenja priobalja, tako i promene ekologije u poplavljenom području.

Ključne reči: *kamena rampa, zahvat vode, životna sredina reke, numeričko modelovanje.*