HYDRAULIC STUDY OF THE NERETVA RIVER
(FROM MOSTAR TO THE BORDER WITH THE REPUBLIC OF CROATIA)

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ABSTRACT

The main purpose of the study about the Neretva river project is the creation of a mathematical model, which will be used for analyzing possibilities of establishing a flood forecast system as well as simulation and presentation of flood waves by using mapping technology.

The basis of this system represents the mathematical model MIKE 11, which is used for the creation of the Neretva river model from the hydroelectric power plant HE Mostar until the border with the Republic of Croatia (i.e. up to the water reservoir (VS) Metković), an area of app. 50 km. The model includes 5 tributaries.

For the purpose of this project, both geodetic and hydrometric surveys have been conducted as well as detailed hydrological analysis, which are used for conducting hydraulic simulations.

Available time series data came from 14 water monitoring stations, for the period from 1995 to 2006.

Hydraulic simulations were made with MIKE 11, which has a possibility of simulating 1-dimensional flow. Flow simulations of steady and unsteady mode were made. A mathematical model calibration was done for both types of flows, followed by verification, and afterwards simulation of selected water waves.

A flow simulation was done in steady mode for the case of the bank protection which is located in the area from VS Počitelj until VS Gabela. It was also done in the case of being without a bank protection on the river Neretva.

An analysis of the flow regime transformation was made in order to evaluate the anthropogenic influence from gravel exploitation.

A flooding map was created by using MIKE 11 GIS based on the obtained steady mode flow simulation results, topographic data and digital maps.

Flood zone mapping creates an important step towards better understanding of flood problems in urban areas, as well as in areas of special interest.

1. INTRODUCTION

The river Neretva and its tributaries is the largest and most significant river in this water area that lies in the area of responsibility of JP for “Vodno područje slivova Jadranskog mora“ (“Catchments areas of the Adriatic Sea”), which ordered this project. It is also one of the larger rivers in Bosnia and Herzegovina.
The river Neretva is 225 km long and runs with its longest part through BH (203 km), and only 22 km through Croatia before inflowing into the Adriatic Sea. It rises underneath the Jabuka mountain in BH. Together with its tributaries, it represents an individual environmental unit and a unique ecological system in this part of world. It rises in the mountainous part of Herzegovina and has features of a mountain river throughout its major part. Because of these features, several hydroelectric power plants have been built: Jablanica, Grabovica, Salakovac and Mostar. Tributaries to the Neretva river are as follows: Ljuta, Rama, Drežanka, Radobolja, Jasenica, Buna, Bregava, Trebižat and Krupa.

On its way to the Adriatic Sea, the Neretva river runs through several cities which are considered as BH’s most beautiful cities, such as: Konjic, Jablanica, Mostar, Čapljina, Počitelj and the Croatian cities Metković and Opuzen. It is famous for its emerald- green colour, clean and entirely drinkable water in its upper flow. The Neretva river flows into the Adriatic Sea in the vicinity of Opuzen within the Neretva delta.

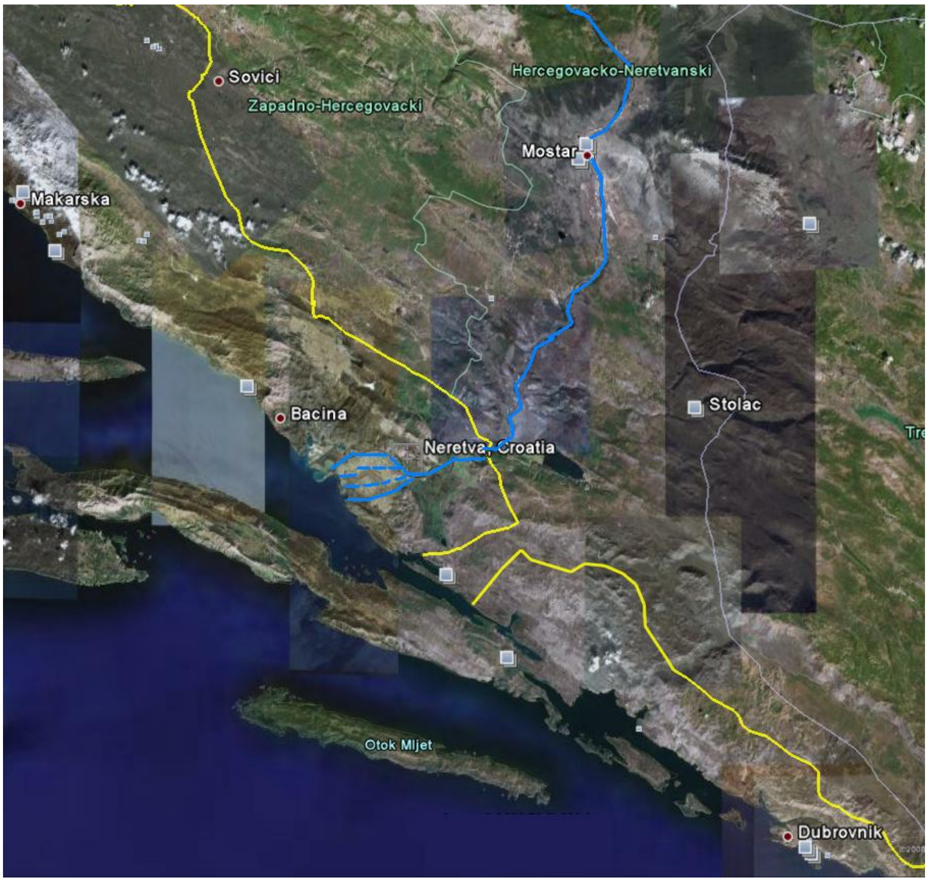


Figure 1 – Orthophoto of the Neretva river at the examined section

The respective section of this hydraulic study is 50 km long and starts at its upstream part at the hydroelectric power plant HE Mostar and runs to the border with the Republic of Croatia, i.e. up to Metković, where the downstream water monitoring station is located.
This project consists of three parts: hydrological analyses, hydraulic calculation and mapping of flooding zones.
According to the project assignment, the hydraulic study should be done in the 1-D model program, i.e. in this case with MIKE 11.

2. HYDROLOGICAL ANALYSES

The basic task of the hydrological analyses is creating historical and current flow curves for the existing automatic hydrological stations at the catchments area of the Neretva river- from Mostar to Gabela, defining water balances (spatial and time distribution of the flow in the catchments) for the selected years based on created flow curves; and calculation of probabilities on high water occurrences (flows and water level) of various recurrent periods for the respective hydrological stations.

Table 1 – Synoptic survey of calculated hydrological parameters which are presented in this elaborate

No.	**VS**	**Flow**	**Flow curve**	**Probability of occurrence HW**	**Water balance 1980. ; 2005/2006.**
1	Mostar	Noretva	*Yes*	*Yes*	*Yes*
2	Baćevići	Noretva	*Yes*	*Yes*	*Yes*
3	Žitomislići	Noretva	*Yes*	*Yes*	*Yes*
4	Gabela	Noretva	*Yes*	*Yes*	*Yes*
5	Dom	Jasenica	*No*	*Yes*	*No*
6	Buna	Buna	*Yes*	*Yes*	*Yes*
7	Stolac-Do	Bregava	*No*	*Yes*	*Yes*
8	Studenci	Trebižat	*No*	*Yes*	*Yes*
9	Stubica	Trebižat	*Yes*	*No*	*No*
10	Humac	Trebižat	*Yes*	*Yes*	*No*
11	Studenci	Studenčica	*Yes*	*Yes*	*No*

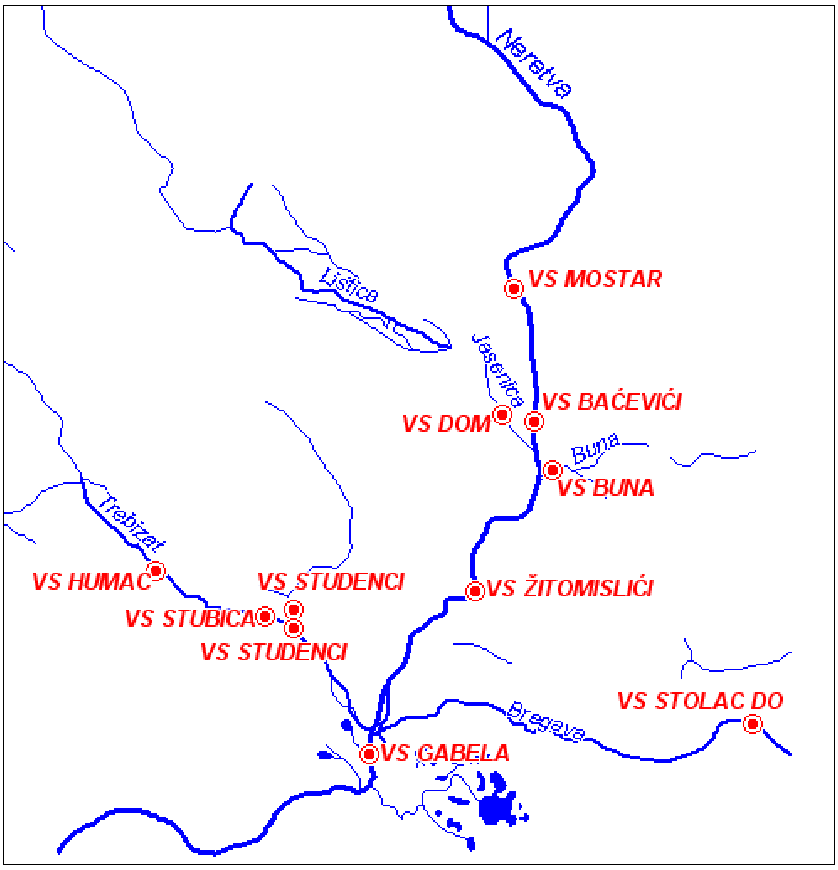
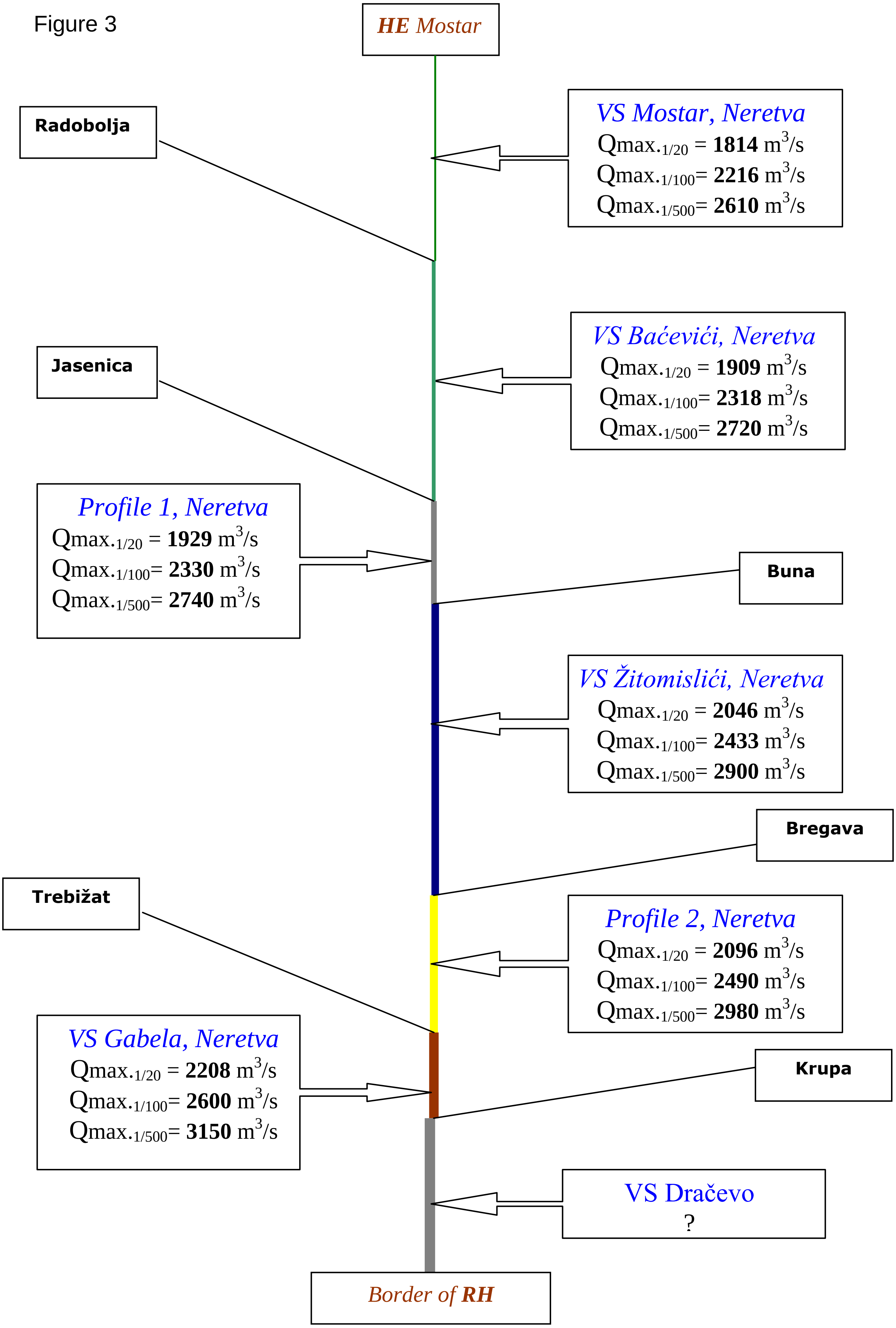


Figure 2 – Cartographic survey of the respective catchments of the Neretva river with appurtenant hydrological stations

The possibility of having large waters of various recurrent periods, which is later on used as input data for stationary hydraulic simulations, is displayed in the following diagram:

Figure 3


HE Mostar
Radobolja
VS Mostar, Neretva
Qmax.1/20 = 1814 m3/s
Qmax.1/100= 2216 m3/s
Qmax.1/500= 2610 m3/s
Jasenica
VS Baćevići, Neretva
Qmax.1/20 = 1909 m3/s
Qmax.1/100= 2318 m3/s
Qmax.1/500= 2720 m3/s
Profile 1, Neretva
Qmax.1/20 = 1929 m3/s
Qmax.1/100= 2330 m3/s
Qmax.1/500= 2740 m3/s
Buna
VS Žitomislići, Neretva
Qmax.1/20 = 2046 m3/s
Qmax.1/100= 2433 m3/s
Qmax.1/500= 2900 m3/s
Bregava
Trebižat
Profile 2, Neretva
Qmax.1/20 = 2096 m3/s
Qmax.1/100= 2490 m3/s
Qmax.1/500= 2980 m3/s
VS Gabela, Neretva
Qmax.1/20 = 2208 m3/s
Qmax.1/100= 2600 m3/s
Qmax.1/500= 3150 m3/s
Krupa
VS Dračevo
?
Border of RH

3. HYDRAULIC CALCULATIONS and ANALYSIS OF RESULTS

3.1. MATHEMATICAL MODEL

Measurements from different water monitoring stations have been available for this project in such a way that boundary conditions of the mathematical model have been determined at their locations. As the time measure data is not the same for each station, several mathematical models have been created for which hydraulic simulations have been conducted later on.
Therefore, we gained geometric models for the following sections:

- HE Mostar – VS Gabela,
- HE Mostar – VS Dračevo,
- HE Mostar – VS Metković,
- VS Žitomislići - VS Dračevo.

The mathematical model also included tributaries of the river Neretva as follows: Radobolja, Jasenica, Buna, Bregava, Trebižat and Krupa.

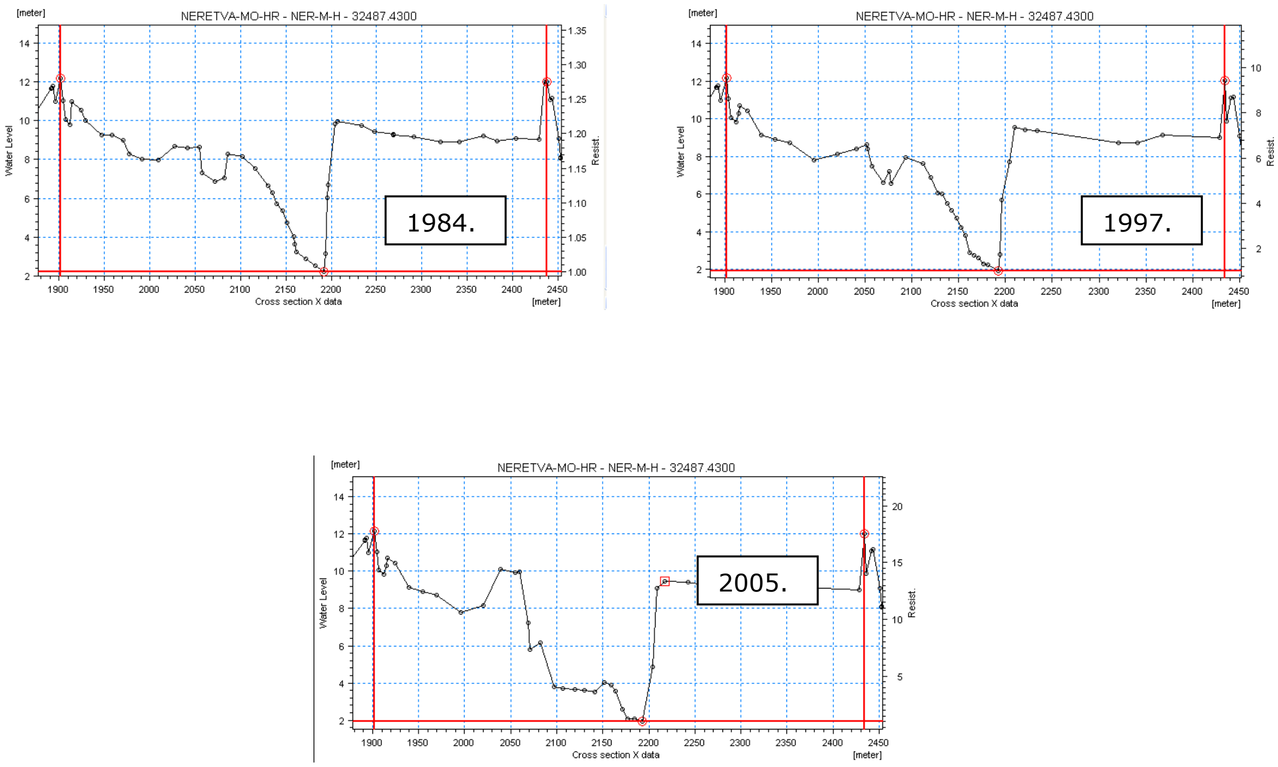
For the area of Počitelj up to the border with the Republic of Croatia where the river bed changes due to anthropogenic influence, it is necessary to repeat the recording of the Neretva river bed quiet often because of gravel exploitation. Hence, we have cross section profiles from 1984, 1997, 2002-2005. At this section, the cross section profiles are recorded with high density (in ca. 200 locations, about every 75m), in comparison with the section upstream of Počitelj towards Mostar (ca. 80 locations, about every 450 m).
It is necessary to define three models which will differ in their year of recoding at the flow analysis due to anthropogenic influence.
The first model is a model that consists of cross section from 1984, the second one is of cross section from 1997 and the third one of cross section from 2003-2005, including cross section from 1997. This all refers to the part from Počitelj to the border with Croatia.
Upstream of Počitelj, the cross sections of all three models are the same, which were recorded after 1998.

In this way, the three models differ from each other:

- Model 1984
- Model 1997
- Model 2003/05

The following figure displays the changes of one cross section profile throughout the year:

Figure 4 – cross sections at chainage 32+487



3.2. BOUNDARY CONDITIONS

The typical upstream boundary condition of the mathematical model of river flows is the hydrogram Q(t) on the specific water wave at non-chainage flow, i.e. constant inflow for chainage flow.
The upstream boundary conditions are defined at all entries into the mathematical model, which means at the upper model boundary of the Neretva river, and at the upper boundaries of all Neretva river tributaries at the examined section.
The downstream boundary condition as the water level diagram h(t), where the water level in the function of time, is usually used as a suitable boundary condition.
On the other hand, the unambiguous value Q(h) is the downstream boundary condition which is required for chainage flow. Furthermore, during the flow simulation, the condition h(t) will generally speaking not always be available, except when it is about reservoirs or tides' conditions.
The tides of the Adriatic Sea have a rather small amplitude. This difference rarely rises over 40 cm in the southern part. However, the tide may rise to a significant height in narrow channels and bays during strong north winds. This phenomenon is characteristic for large and deep bays of the southern Adriatic Sea. The sea phases consist of a mixed type and their amplitudes are quiet irregular. The Q(h) condition is therefore used as the downstream boundary condition for chainage flow, while h(t) is used as the downstream border condition for non-chainage flow.

3.3. CALIBRATION AND VERIFICATION OF THE MATHEMATICAL MODEL OF THE NERETVA RIVER

The calibration of the unsteady flow consists of adjusting model features in such a way to gain coincidences between measured and simulated time dependant hydrograms. The water level diagram is in this case particularly emphasized due to the fact that flows are never precise or accurate and are rarely recorded for the entire flooding period. In the same time, the water level in the function of time is mostly accurate at the majority of locations along the river flow. The measured unsteady flows might be used for additional verification at the calibration. By having available the measurement data from the water monitoring stations at the Neretva river and its tributaries from HE Mostar to VS Metković, seven historical events from 1995-2005 have been selected as well as one extracted historical event for which a model verification has been conducted. They are as follows:

Table 2 – events for which the calibration of the model has been conducted

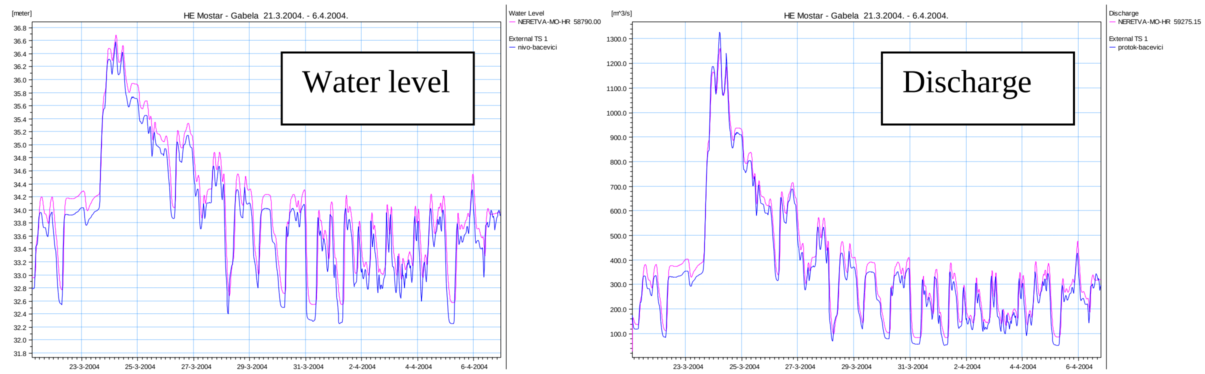
Simulation start	**Simulation end**	**Simulation duration (days)**	**Section**	**Upstream boundary condition**	**Downstream boundary condition**
12.12.1995.	22.4.1996.	130	Žitomislići-Dračevo	Q(t) VS Žito.	H(t) VS Dračevo
15.12.1999.	20.12.1999.	5	HE Mostar–Gabela	Q(t) VS Mostar	H(t) VS Gabela
9.10.2002.	16.10.2002	7	Žitomislići-Dračevo	Q(t) VS Žito.	H(t) VS Dračevo
21.3.2004.	6.4.2004.	15	HE Mostar–Gabela	Q(t) VS Mostar	H(t) VS Gabela
10.4.2004.	11.5.2004.	31	HE Mostar–Gabela	Q(t) VS Mostar	H(t) VS Gabela
27.3.2005.	10.5.2005	44	HE Mostar–Dračevo	Q(t) VS Mostar	H(t) VS Dračevo
25.12.2005.	11.1.2006.	17	HE Mostar–Dračevo	Q(t) VS Mostar	H(t) VS Dračevo

Table 3 – event for which the verification of the model has been conducted

Simulation start	**Simulation end**	**Simulation duration (days)**	**Section**	**Upstream boundary condition**	**Downstream boundary condition**
30.11.2004.	7.12.2004.	7	HE Mostar-Metković	Q(t) VS Mostar	H(t) VS Metković

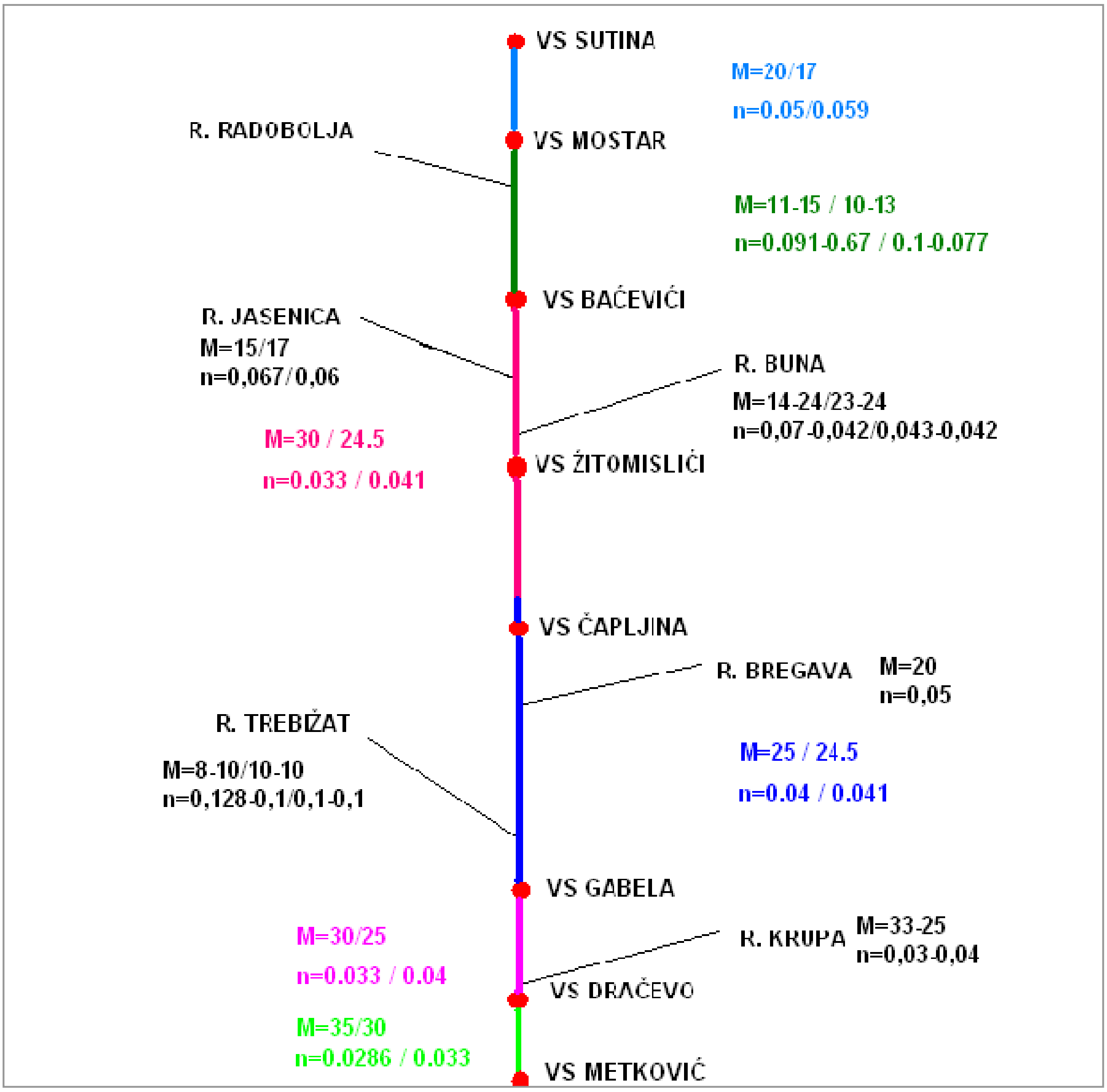
The following figure displays only one result of the calibration of unsteady flow, for one location, i.e. VS Bačevići:

Figure 5 measured simulated



Manning's numbers M have been used in the mathematical model of the Neretva river, which values are marked at the schematic display as shown in figure 6.

Figure 6



3.4. HYDRAULIC CALCULATION FOR STEADY FLOW, FOR FLOW OF RANK 1/20, 1/100 AND 1/500 YEAR

Steady flow has been conducted for two different scenarios: in cases with embankments (which is the real case) and without embankments.
Simulations have been conducted for water waves of the recurrent period 20, 100 and 500 years, which are defined by the Hydrologic analyses of the Neretva river.

Figure 7 – Schematic display of the determined boundary conditions for RP=100 g.

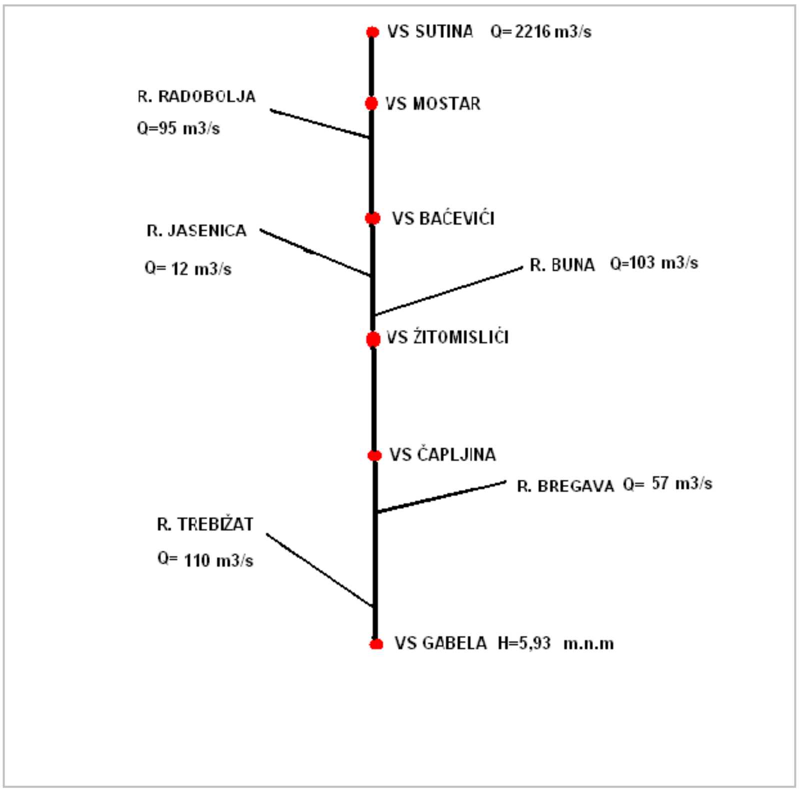


Figure 8 –Longitudinal section of the Neretva river with marked maximum water level for RP=100 years

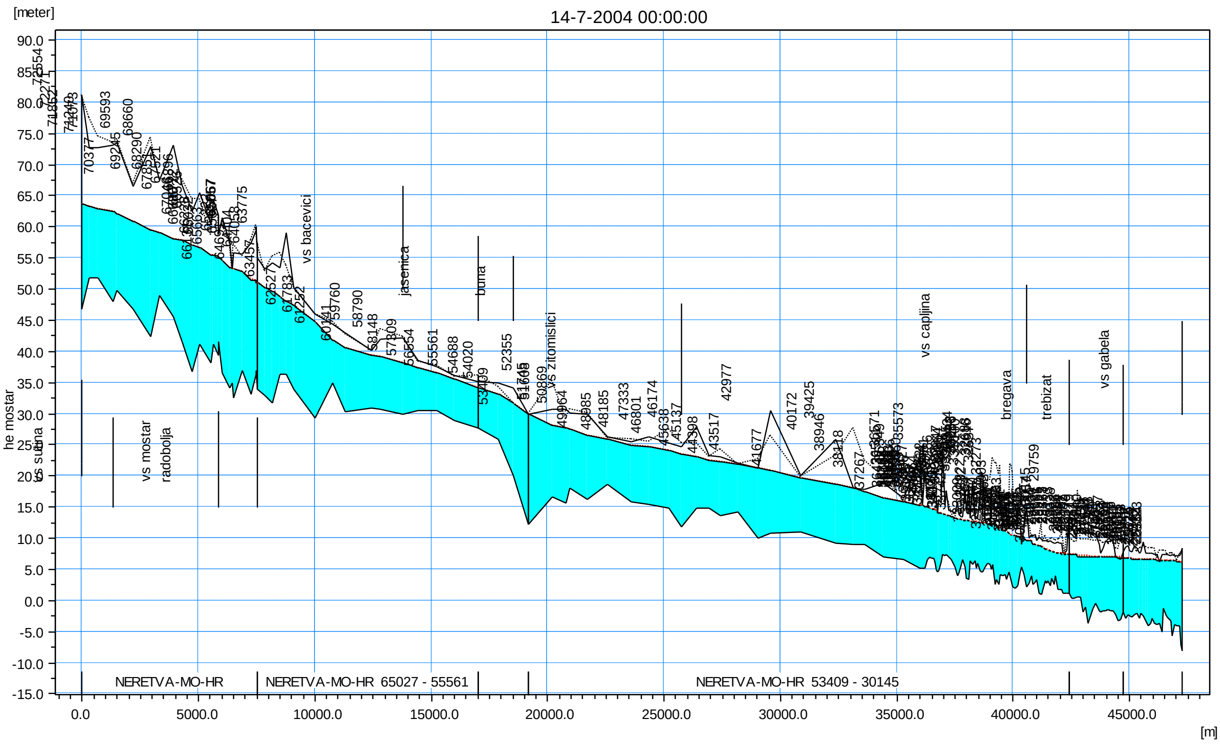
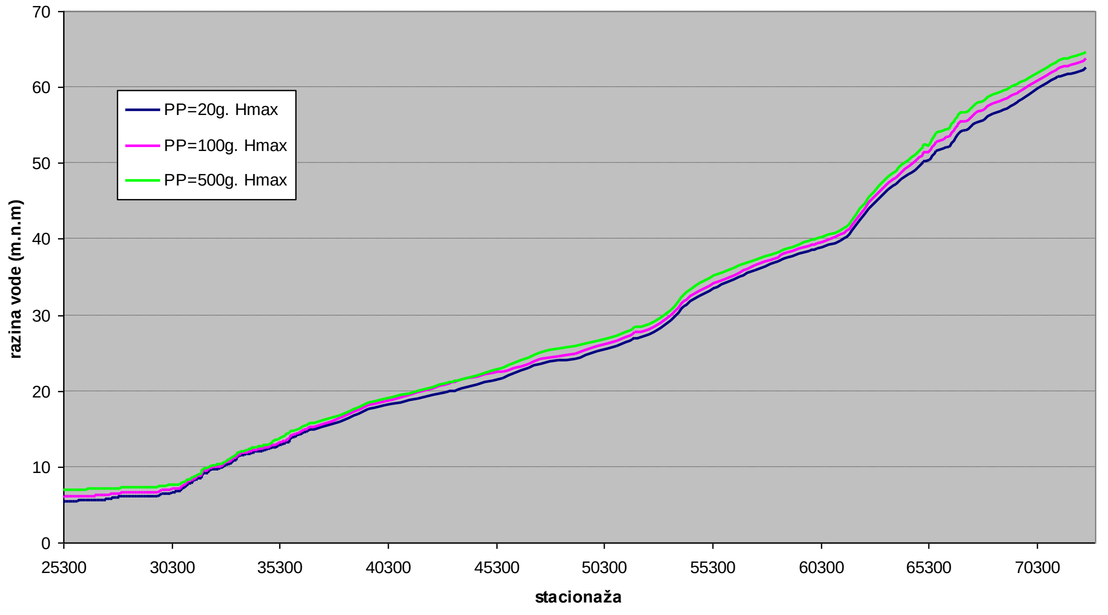


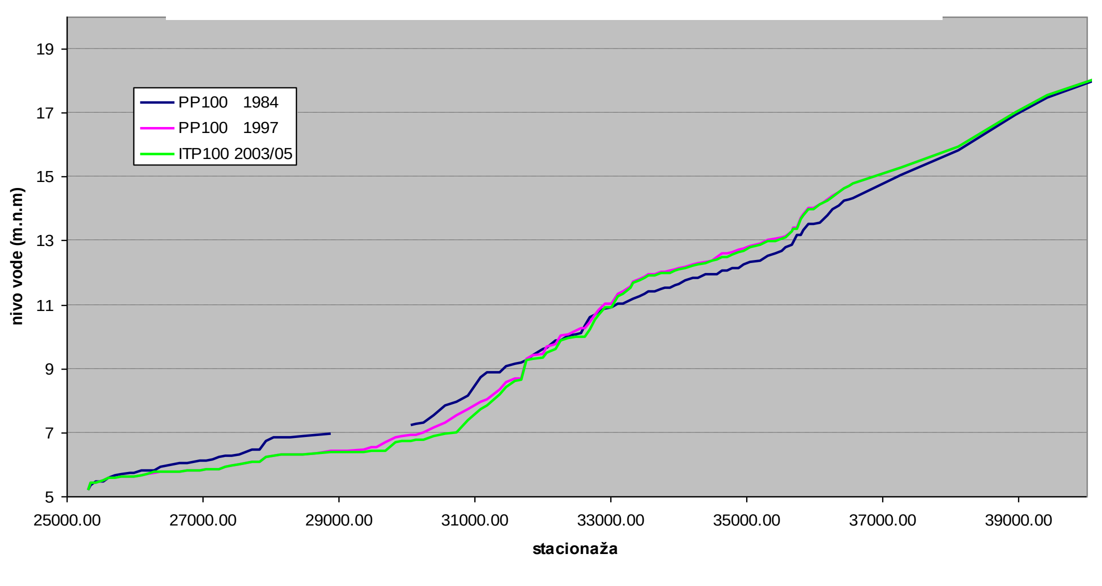
Figure 9 –Water levels for steady flow without enbankments, recurrent periods 20, 100, 500



3.5. ANALYSIS OF THE CHANGES IN THE FLOW REGIME IN ORDER TO EVALUATE THE ANTHROPOGENIC INFLUENCE DUE TO GRAVEL EXPLOITATION ALONG THE SECTION FROM THE BORDER TO ČAPLJINA

Cross section profiles from three different time periods have been available for the analysis of the anthropogenic influence due to gravel exploitation. Based on gained results from the hydraulic simulations, it is visible that the border is at chainage 33 km where the tendency of changes in the water surface level shifts.
With time, the river bed is becoming deeper downstream of that chainage, so that the maximum level of the water is at the lowest for model 2003/05, regardless of the water wave rank.
Upstream of the 33 km at the Neretva river is the highest water level for model 2003/05, which chronologically speaking means that it has a tendency of rising.
All this is only valid under the assumption that the riverbed is as measured in 1997, i.e. that the flow curve at VS Gabela and for the other models is as it was defined in the hydrological analysis.

Figure 10 – Antropogenic influence



4. MAPPING FLOODS

Within the project “Hydraulic study of the Neretva river”, one of the assignments was the cartographic layout of hydraulic simulation results which, combined with orthophoto maps and 3D Digital Elevation Model (DEM) in shapes as lines, contour lines and individual dots, give a survey on the events during floodings in different versions that represent the flows of the recurrent periods 20, 100 and 500 years.

The digital map of the area which was used to determine the flooding area was created by using all available geodetic and GIS documents as follows:

1. Cross section profile of the Neretva river and its tributaries, gained by geodetic recording, from chainage km. 20+705 – st. 73+500 in ACAD format, from where they were translated into table format which is suitable for using it in the MIKE11 Cross Section Editor.
2. Different geodetic records of the Neretva river bed where heavy gravel exploitation occurs (control records) in ACAD format
3. 3D Digital Elevation Model (DEM) that is defined by lines, contour lines and individual dots at the examined section up to above the level of the 500 year water by developing the digital orthophoto
4. colored DOF in the scale 1:5000 of the entire area
5. colored DOF in the scale 1:1000 of part of the area (from the RH border to beyond the city Čapljina).

Geodetic profiles are used in cases when they exist (riverbed and surrounding, mostly up to the embankment, but not always. For parts where the geodetic profile is missing, data from the DEM follows up. In this way, a model has been created which is used in mapping.
70 maps (dimensions 90/60) have been created as the result of mapping flooding zones of certain recurrent periods and models with existing bank protections and without them, similar to this one:

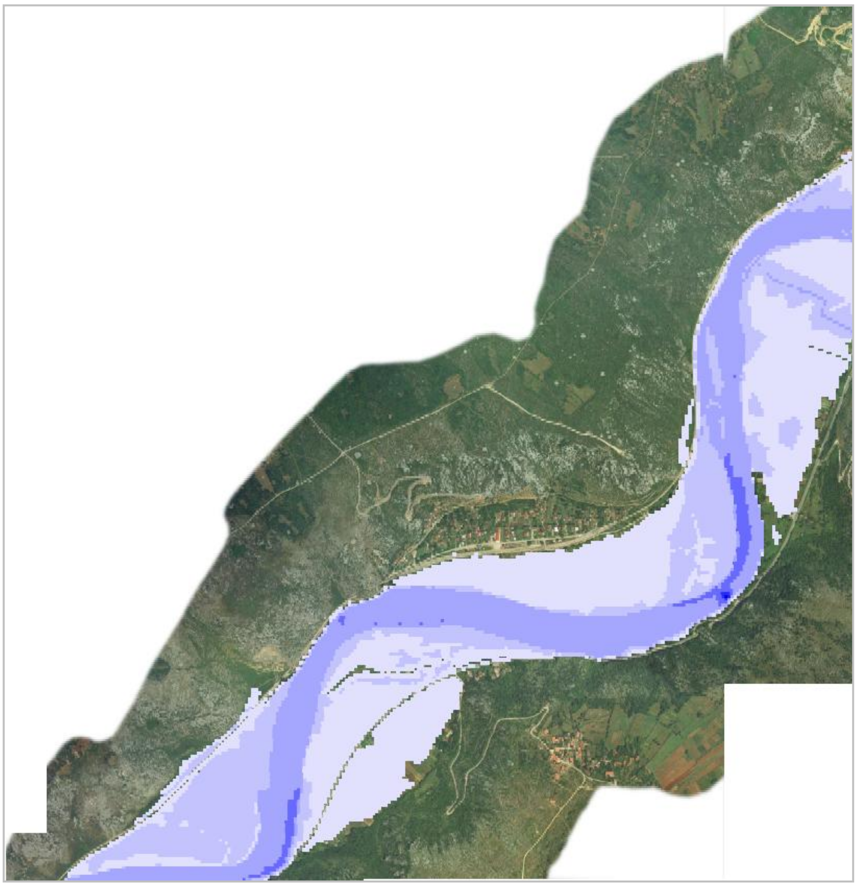


Figure 11