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FLOOD FREQUENCY MODELLING OF THE KOPAČKI RIT NATURE PARK

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Original scientific paper
Kopački rit Nature Park, as a valuable wetland area in the Republic of Croatia, was very often the subject of different investigations. Most of them were dealing with biodiversity and its biological values. There is only a small number of investigations on the Kopački rit water regime, basis of the existing ecosystem, and its flooding impacts on the variety and existence of its species. This paper gives a contribution to the hydrological research of Kopački rit by the analysis of its flooding frequency depending on the Danube River water level in the upstream section from 1380 rkm to 1433 rkm. Also, it pays attention to the importance of the flooding regime for the survival of its biological communities. Fluctuations of discharges cause changes in water velocities and shear stress which have influence on processes of erosion and sedimentation. Results obtained in the paper are the magnitude of flooded areas and the volume of water spread in the floodplain and the Nature Park for the floods of 5, 10, 25, 50 and 100 years return periods.

Keywords: *flood return period, frequency of flooding, Kopački rit Nature Park*

Modeliranje učestalosti plavljenja Parka prirode Kopački rit

Izvorni znanstveni članak
Park prirode Kopački rit, kao izuzetno važno močvarno područje na prostoru Republike Hrvatske, zastupljeno je u brojnim dosadašnjim istraživanjima. No, ona su se uglavnom odnosila na biološku raznolikost i samo posredno na utjecaj plavljenja na brojnost i raznolikost vrsta u Parku prirode Kopački rit. Vrlo je malo istraživanja koja su se bavila samim vodnim režimom Kopačkog rita, osnovom postojećeg ekosustava. Ovim radom daje se doprinos hidrološkim istraživanjima Kopačkog rita analizom pojavnosti plavljenja šireg područja Parka prirode Kopački rit u ovisnosti o visini vodostaja rijeke Dunav na dionici od 1380 rkm do 1433 rkm. Također se ukazuje na važnost plavljenja za opstanak bioloških zajednica toga prostora. Ovisno o iznosu protoka mijenjaju se i brzine strujanja vode unutar Kopačkog rita, kao i vučne sile koje utječu na procese erozije i sedimentacije. Rezultat rada su ploštine plavljenih površina i volumen izlivene vode dolaskom velikih voda različitih povratnih razdoblja, 5, 10, 25, 50 i 100 godina.

Ključne riječi: *Park prirode Kopački rit, povratna razdoblja, učestalost plavljenja*

1 Introduction

Kopački rit Nature Park is extremely important wetland with valuable and rich biodiversity. It was recognized 45 years ago and it was protected by law in 1967. In 1993, Kopački rit was protected by the Ramsar Convention and came on the list of the internationally important wetlands. In the area of about 18 000 ha, more than 2000 species are registered. It is located between the Drava River and the Danube River and its existence and ecological equilibrium depend on flooding regime of the Danube River, while the Drava River has significantly less importance [1, 2]. Although the Drava and Danube water regimes are the basis of existence of the Kopački rit wetland, the first comprehensive investigations of its hydrological characteristics were undertaken at the end of the seventies. They have lasted until nowadays due to the extremely complex and dynamic hydrological and hydraulic behaviour of the area. Besides, by moving of the Drava mouth to the Danube and of the main Danube watercourse too inside Kopački rit, parts of the land and the water areas have changed their magnitude, shape and function, depending on floods [3].Biological communities of natural wetlands, like Kopački rit, are very sensitive to the variations of various mutually connected processes which respond to external factors and influences. One of the most important is climate change which affects variations in the run off, number of biological species, sediment and nutrition transports, etc. [4]. Also, human impacts cannot be neglected because in the last 45 years, numerous hydro technical works and structures have been done. Some of them have had a negative impact on water regime [5]. Dynamics of the Drava and the Danube water bed shaping is very much different compared to their natural state. Regulation waterworks have shortened the watercourse and hydraulic gradients are bigger, resulting in more intensive erosion processes [6]. Also, depending on water quantity and flood intensity, water balance components are changing. During high water levels, inflows and outflows influenced by the Drava and Danube Rivers are dominant (horizontal components of water balance). During small and average water levels, vertical components of water balance, such as precipitation, evaporation and transpiration, become dominant [7, 8].

Inside the Kopački rit, water comes from four sides, but the Danube River brings the biggest water volume, especially its high water discharges [9]. That is the reason why this paper deals with the area of the Nature park Kopački rit and the Danube floodplain section from 1380 rkm to 1433 rkm. This section corresponds to the area from the state border between the Republic of Hungary and the Republic of Croatia to the mouth of the Drava River to the Danube River (3 km downstream).

The considered section of the Danube River includes the sector Apatin (Serbia) and Vemelj–Petreš and Aljmaš (Croatia). The Kopački rit Nature Park exists in between these sectors. Some parts of this Danube section are critical considering water bed stability, navigation conditions and the load and ice transport [10, 11]. Depending on the analysed return periods, flood maps, water velocity and shear stress maps have been developed.

2 Input data

Hydraulic analysis has been made by the mathematical model HEC-RAS. It requires data of terrain geometry and watercourse axis processed by HEC-

GeoRAS toolbar in ArcGIS, data of watercourse cross sections and water level data of the Danube and the Drava Rivers. Mathematical modelling of the considered Danube section was made for steady state flow and calibration was made for unsteady state flow. Figs. 1, 2 and 3 give different maps of analysed areas: overview map with marked gauging stations, analysed area with borders of the Kopački rit Nature Park and geometrical characteristics of the Danube and the Drava Rivers prepared for modelling. Cross sections are defined for each 200 m and they are perpendicular to regulatory axis and stream direction in floodplains [12].

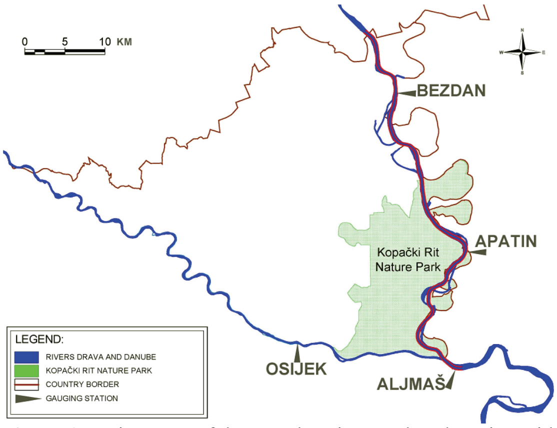

Figure 1 Review map of the Danube River analysed section with stations

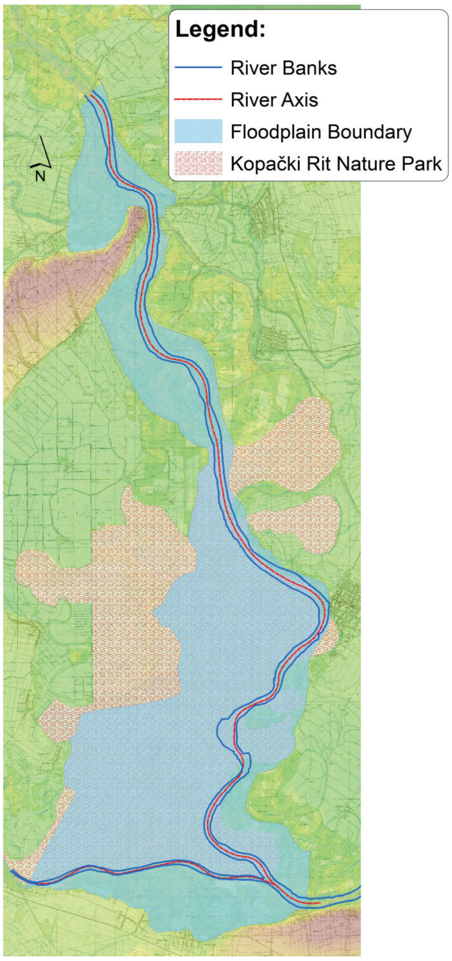

Figure 2 Review map of the observed area

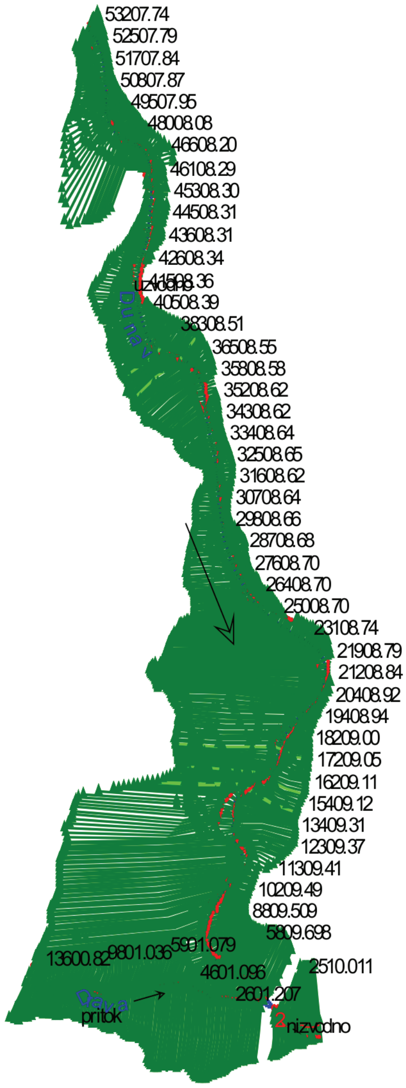

Figure 3 Geometry of the River Danube prepared for modeling (HEC-RAS)

For hydraulic modelling, the most sensitive parameter is the roughness coefficient of floodplains which depends on land use, or vegetation cover. The vegetation cover was defined by CORINE Land Cover 2000 of Croatia data base. The CORINE Land Cover of Croatia (CLC) is a digitized data base of land cover according to CORINE nomenclature, consistent and homogenized with the EU data [13].

3 Hydrological analysis of discharges and water levels

Previous investigations defined that flood frequency is 1 ÷ 2 per year, mostly from February to May, and small water episodes come in the period from August to January. Also, the characteristic Danube water levels were obtained. Above 81,50 ma.s.l. water enters Kopački rit and remains in bigger canals, swamps and lakes. When the water level exceeds the height of 82,00 ma.s.l. filling of smaller canals starts. The key level for the Kopački rit Nature Park is 82,50 ma.s.l., when northern part of the area connects with its southern part. When water level reaches the height of 83,00 ma.s.l., the whole area of Kopački rit is under the water [9]. All these characteristic water levels are defined according to the Apatin gauging station (Serbia).

Flood waters of different return periods were determined by using data of maximum annual discharges of the Drava and Danube Rivers. The Drava discharges were measured at the Donji Miholjac station in the period from 1951 to 2008. The data of the Danube discharges (Fig. 4) measured at the Bezdan station (Serbia) in the same period were used as well as the data of water levels measured from 1921 ÷ 2008 (Fig. 5). Missing data of both parameters are from 1991 to 1998. Hydrological contribution of the Drava River to Kopački rit is much smaller than that of the Danube, so it was included and analysed in the modelling only as the Danube tributary.

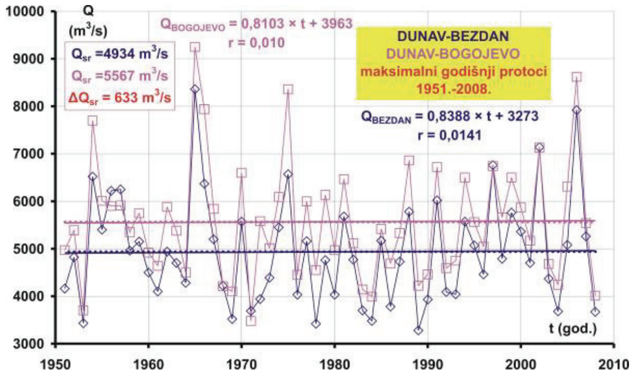

Figure 4 Maximum annual discharges data series of the Danube River, observed at the Bezdan and Bogojevo stations from 1951 to 2008 [14]

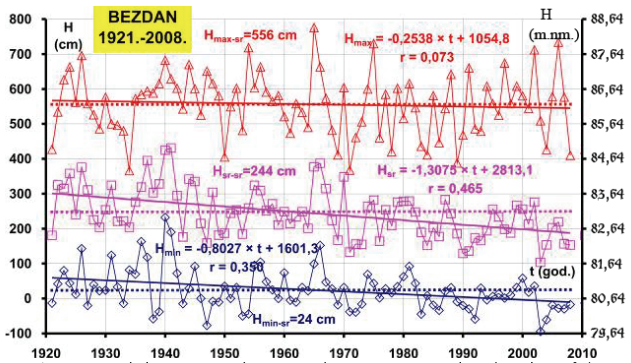

Figure 5 Minimum, maximum and average water level series of the Danube River, observed at the Bezdan station from 1921 to 2008 [14]

These data were analysed by several distributions (Fig. 6) in order to achieve the Danube River discharges and water levels of 5, 10, 25, 50 and 100 return periods. As Log-Pearson III distribution is recommended for flood frequency analysis, it was chosen as the most appropriate for the analysis. The main advantage of this method is its successful application to relatively short time series in order to obtain floods for much longer return periods. The values of the Danube River water levels and discharges of 5, 10, 25, 50 and 100 years return periods are given in Tab. 1. The equation and parameters of Log-Pearson III distribution are [15]:

$$\lg x_{\mathrm{PR}} = \overline{\lg x} + K \cdot \sigma \cdot \lg x, \qquad (1)$$

where are:

x_{PR} – variable value relevant for different return periods

x – random variable (discharge, water level)

$\overline{\lg x}$ – mean value of logarithms of random variables

K – frequency coefficient. It is in a function of skewness coefficient C_s and return period

σ – standard deviation.

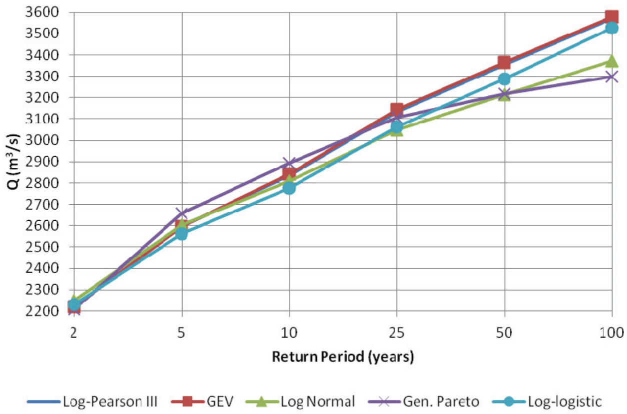

Figure 6 Values of the Danube River discharges obtained by differnt distributions

Table 1 Determination of the relevant Danube River water levels and discharges of different Return Periods

Return Period (year)	H (ma.s.l.) Aljmaš	Q (m³/s) Bezdan
5	84,79	5762
10	85,38	6417
25	86,05	7239
50	86,52	7852
100	86,95	8464

4 Model calibration

Previously elaborated input data were the basis for establishing a nominal hydraulic model and developing the calibration process. The calibration was performed by varying Manning's roughness coefficient for the main watercourse and for the floodplain area. The observed and simulated water levels were compared. The comparison of the measured and modeled water levels was made for the reference profiles of the Batina and Apatin gauging stations.

From the hourly discharges and water levels data measured in 2009 at the gauging stations Batina, Bezdan, Apatin and Bogojevo, boundary conditions for nine episodes were isolated and used in calibration (Fig. 7).

For each episode several simulations were performed by varying Manning's roughness coefficient for the main watercourse and for the floodplain area until satisfactory accuracy was achieved (± 2 cm of difference in water levels). A wide range of water levels of the Danube River was covered through these nine episodes.

5 Modelling results

Some of the results were observed by HEC–RAS software, and the other ones were processed by ArcGIS using HEC-GeoRAS toolbar. Results that include distribution of discharges, velocities and water levels for different return periods were obtained by hydraulic analysis in HEC-RAS software. These output data can be further analysed by individual cross sections, longitudinal profiles, graphs and tables. Nevertheless the HEC–RAS software allows three-dimensional display of water levels according to the observed return period. Distribution of water depths and velocities with associated maps and flooded areas was observed using HEC-GeoRAS toolbar. The reason is better display quality.

Water level of 82,5 ma.s.l. is refered to as boundary one when the inflow from the Danube River in the Kopački rit Nature Park starts. The range of water levels is between 2,29 cm for 5 years return period and 4,45 cm for 100 years return period with corresponding flow data (Fig. 8).

Mean profile water velocities in the Danube River upstream from the Drava mouth vary from 0,5 m/s to 1,8 m/s, depending on return period (Fig. 9). Downstream of the Drava River mouth to the Danube, velocities are from 1,2 to 1,55 m/s.

On the contrary, velocities of water in floodplain, after flooding, are very low and the maximum one is 0,2 m/s (Fig. 10).

With these results, conclusions of previous researches are confirmed [9]. According to them, maximum velocity, around 1 m/s, appears at the time of overflowing from canals and swamps. Also, in the phase of charging the Kopački rit Nature Park, velocities decrease to the range of 0,2 to 0,5 m/s.

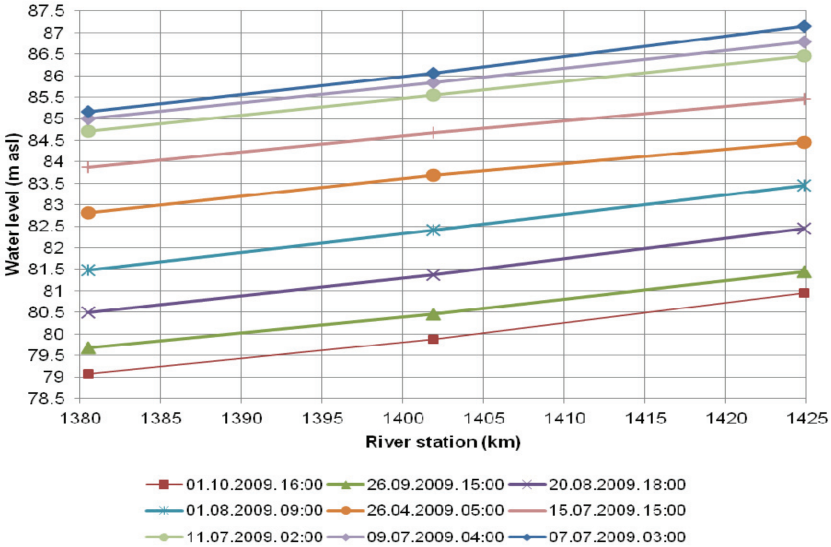

Figure 7 Display of different water levels for episodes used for calibration from Batina to Aljmaš

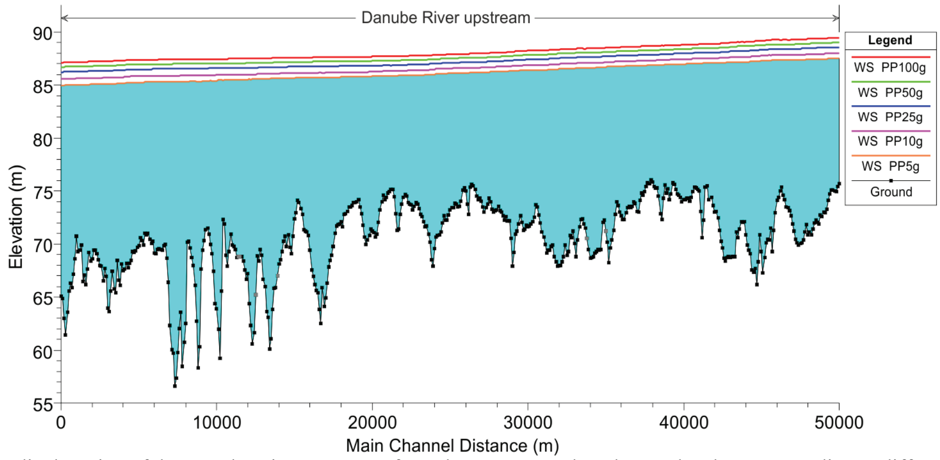

Figure 8 Longitudinal section of the Danube River upstream from the Drava mouth and water levels corresponding to different return periods

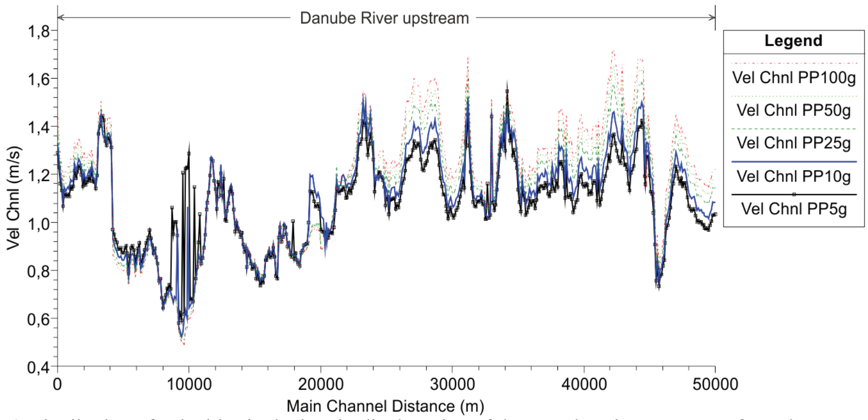

Figure 9 Distribution of velocities in the longitudinal section of the Danube River upsretam from the Drava mouth

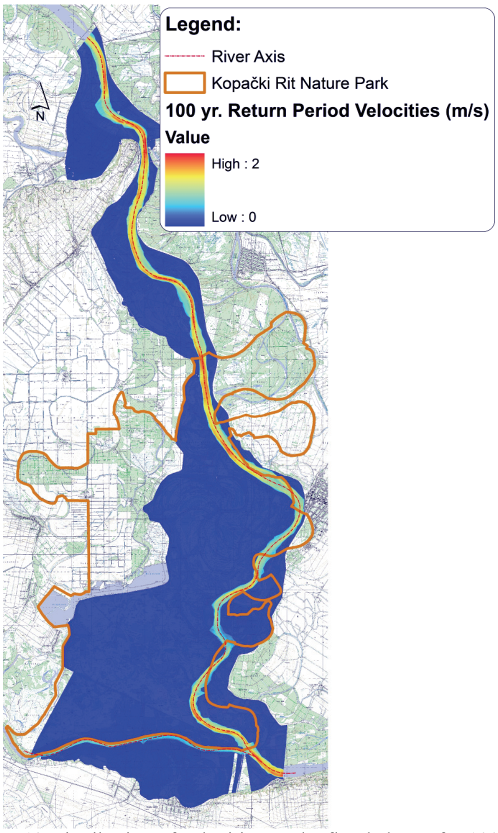

Figure 10 Distribution of velocities on the flooded area for 100 years return period

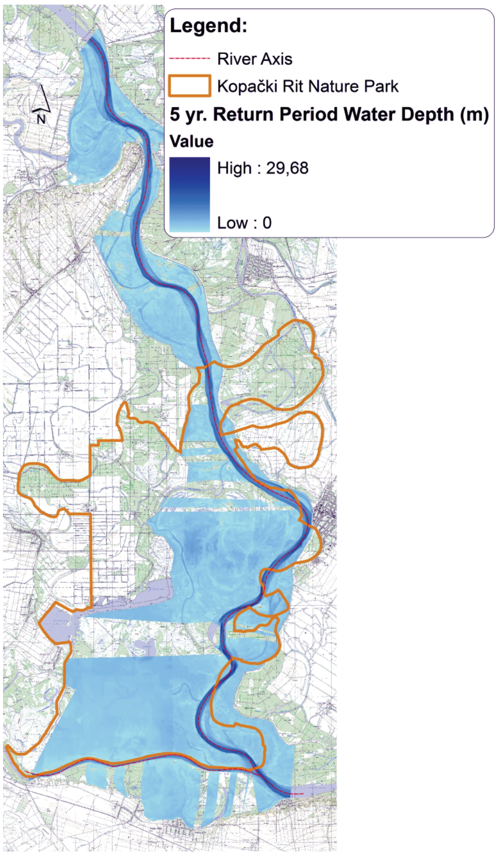

Figure 11 Map of the flooded area for 5 years Return Period

6 Characteristics of the flooded area

Output data processing was done separately for the floodplain area of the observed section of the Danube River and for the area of the Kopački rit Nature Park. Analysis of the floodplain area data and the data for the Kopački rit Nature Park showed similar results. The sizes of the flooded area depend on return period, but their variations are very small. For 5 and for 100 years return period flooded area of the Danube floodplain is 128 km^2 (Fig. 11), and 155 km^2, respectively (Fig. 12). Increase of the total size of the flooded area is less than 18 %. Considering flooded area only in the Kopački rit Nature Park, increase is nearly 20 %. Obtained values refer to the right side of the Danube floodplain.

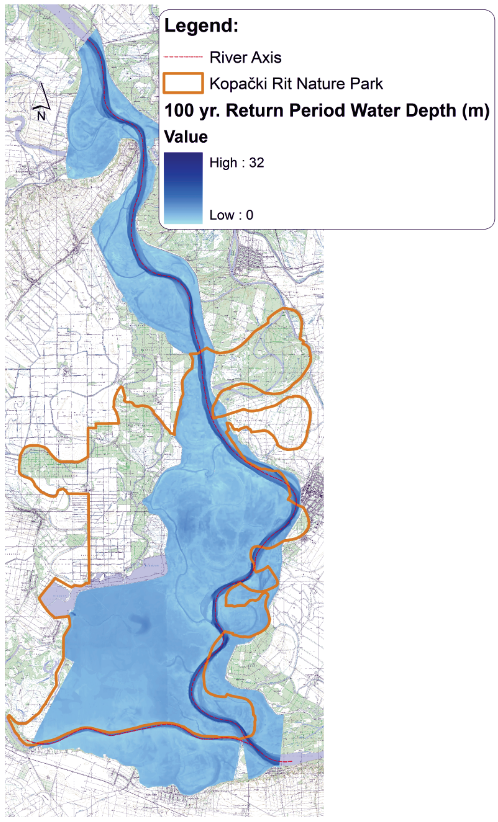

Figure 12 Map of the flooded area for 100 years Return Period

That means that every time the flood comes, regardless of the return period, almost the entire area of the Kopački rit Nature Park, from bank to bank, is under water.

There is hardly any flooded area in time of average water levels. According to the observed data from the period 1951 ÷ 2008, average water level of the Danube River is 81,75 ma.s.l. During that water level, there is water just in some depressions and lakes. In other words, 1,35 km^2 of the Danube River floodplain is under water and only 0,7 km^2 of the Kopački rit Nature Park, what is not enough for the survival and life of many species (Fig. 14). During average water level, the volume of water in the Kopački rit is about 0,47×10^6 m^3.

Flooded areas during floods or high water levels are shown in Tab. 2 and Fig. 14. For the Kopački rit Nature Park itself, the size of the flooded area is more or less constant after the flood of 25 years return period which means that the entire area of the Kopački rit Nature Park is under water. During floods of 5 and 10 return periods, only elevated terrain remains above water.

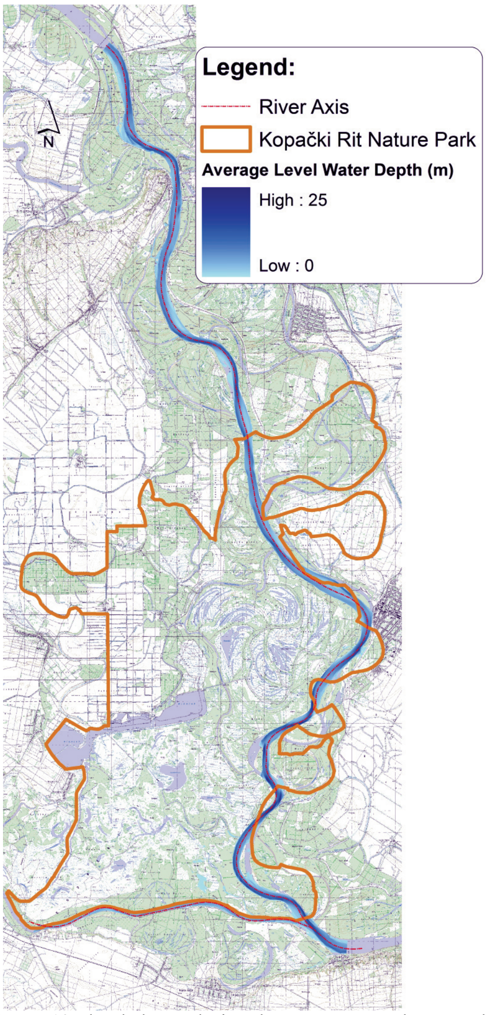

Figure 13 Flooded area during the average Danube water level

Table 2 Flooded areas for different return periods for floodplain of the observed section of the Danube River and for the area of the Kopački rit Nature park

Return period (year)	Danube floodplain (km^2)	Kopački rit Nature Park (km^2)
5	127,91	94,82
10	147,33	112,81
25	153,83	118,88
50	154,91	119,87
100	154,98	119,90

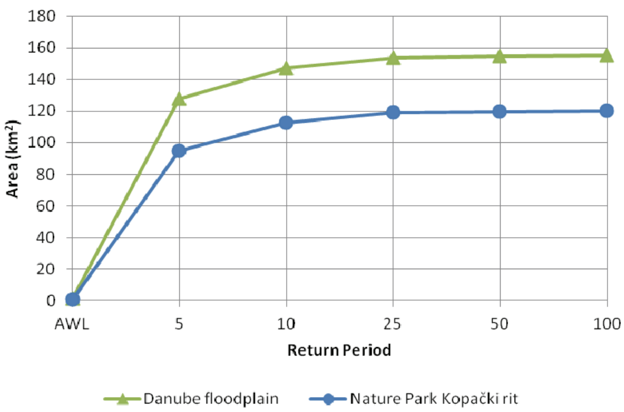

Figure 14 Relation between the flooded floodplain area and the flooded area of the Kopački rit Nature Park for different Return Periods

Difference in the flooding water volume for different return periods is much more significant, as shown in Tab. 3 and Fig. 15.

Table 3 Volume of flooding water for the floodplain of the observed section of the Danube River and for the area of the Kopački rit Nature Park

Return period (year)	Danube floodplain ($\times 10^6$ m^3)	Kopački rit Nature Park ($\times 10^6$ m^3)
5	329,83	252,51
10	460,84	363,8
25	571,78	454,00
50	643,83	510,81
100	710,13	562,24

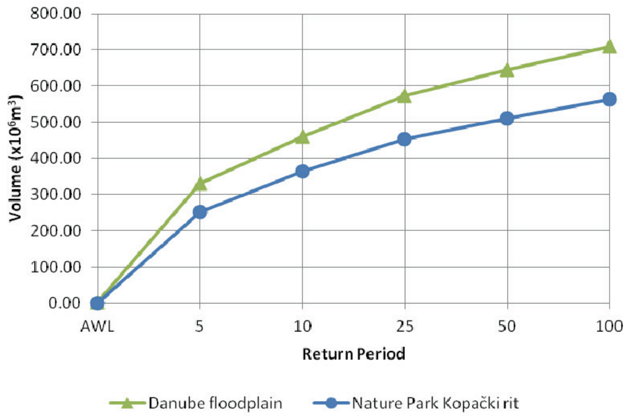

Figure 15 Display of volume of water for different Return Periods

7 Conclusion

Because the Kopački rit Nature Park occurs due to the Danube River and the Drava River and the Danube flooding periods, high water levels and maximum discharges are extremely important. Great biodiversity of that area is also the result of the exchange of floods and water withdrawal. Water depth and duration of floods have significant influence on the life of all present species in the Park [16].

In order to maintain current state of the Park, it is very important that intensity and frequency of floods do not decrease. For this purpose, the trend of characteristic annual water levels of the Danube River near Bezdan has been observed. It is concluded that there is no downward trend in the series of maximum annual water levels. There are just variations during the observed period (1921-2008). Downward linear trends in the series of average and low water levels are statistically significant. Their lowering is from 1,3 cm/year to 0,8 cm/year.

By observing annual maximum discharges of the Danube River near Bogojevo and Bezdan, which were analysed in this paper, the same conclusion has been reached. There is no decreasing of maximum discharges during the observed period (1951 ÷ 2008). That fact is of great importance for flooding of the Kopački rit Nature Park.

In this paper, one-dimensional model which analyses the flow just in the direction perpendicular to the cross section was used. For more detailed and accurate results, the flow in all directions should be observed. That is enabled by two-dimensional and three-dimensional software packages. Although detailed images of the whole area were not available, it is obvious that a considerable part of the Park is under water even during 5 years return period floods. Increase of the volume of spilled water is much more noticeable than the size of the flooded area.

We consider that this paper can improve the existing knowledge of hydrological and hydraulic features of the Kopački rit Nature Park. This paper re-emphasizes the importance of flooding periods of the Kopački rit Nature Park and the dependence of this complex ecosystem on the appearance of high water.

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