ASSESSMENT OF THE ZAGREB TOWN FLOOD DEFENCE IN NEW CONDITIONS

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A low laying part of the croatian capital town Zagreb is exposed to the Sava River flood risk. The Sava riverbed passes through its urban area. The biggest flood occured on 26 Nov. 1964. To prevent the Zagreb town from the Sava River floods until the end of 1978 flood control system was constructed. The paper gives assessment of the Zagreb town safety from floods in new conditions. For this reason the series of maximum annual Sava River water levels and discharges measured at the gauging station Zagreb from 1926 to 2000 are analysed.

Introduction

A region of croatian capital town Zagreb is especially exposed to flood risk. The Zagreb town (775 424 citizens according to the 2001 census) is situated along the south slope of the Medvenica mountain as well as in the Sava River valley. Such a location required flood protection from the Sava River as well as from flash floods of the Medvenica mountain seventeen torrential creeks. A low laying part of town is enadangered by the Sava River floods.

The Zagreb town was suffered from the Sava River floods. The first recorded one was on 29 September 1469. The next large floods were registrated as follow: 26 July 1651, 1770, 15 May 1876, 27 March 1895, 29 June 1923, 12 November 1925, 25 June 1926, 10 August 1926 and 25 September 1933.

The most catastrofic flood of the Zagreb town caused by the Sava River occured on 26 November 1964. The river embankment was destroyed on several places and watre flooded about 60 km^2 of the Zagreb town region. Its maximum discharge was 3126 m^3/s and maximum water level was 514 cm or 117.40 m a.s.l., which is 69 cm higher than during second big flood wich was on 24 September 1933, when the maximum discharge was 2877 m^3/s.

The 1964 year flood caused serious damage. Seventeen persons died. About 40 000 were evacuated, 3 300 industrial properties and 10 000 apartments were destroyed etc. The flood damage is estimated to more than 100 million US $.

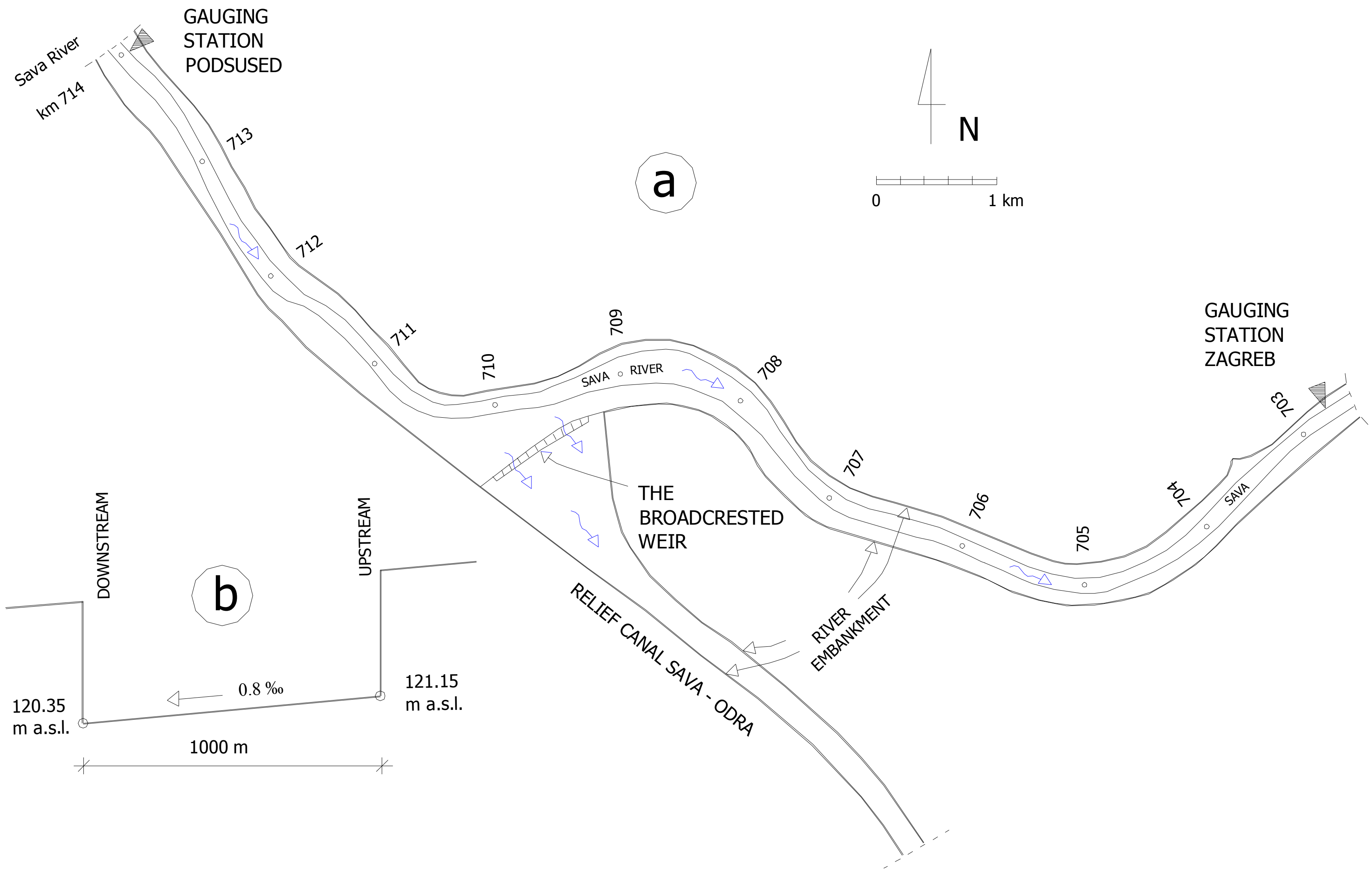

Figure 1 Map of the Sava River and main parts of the flood control system (a);
Cross section of the Jankomir broadcasted weir (b)

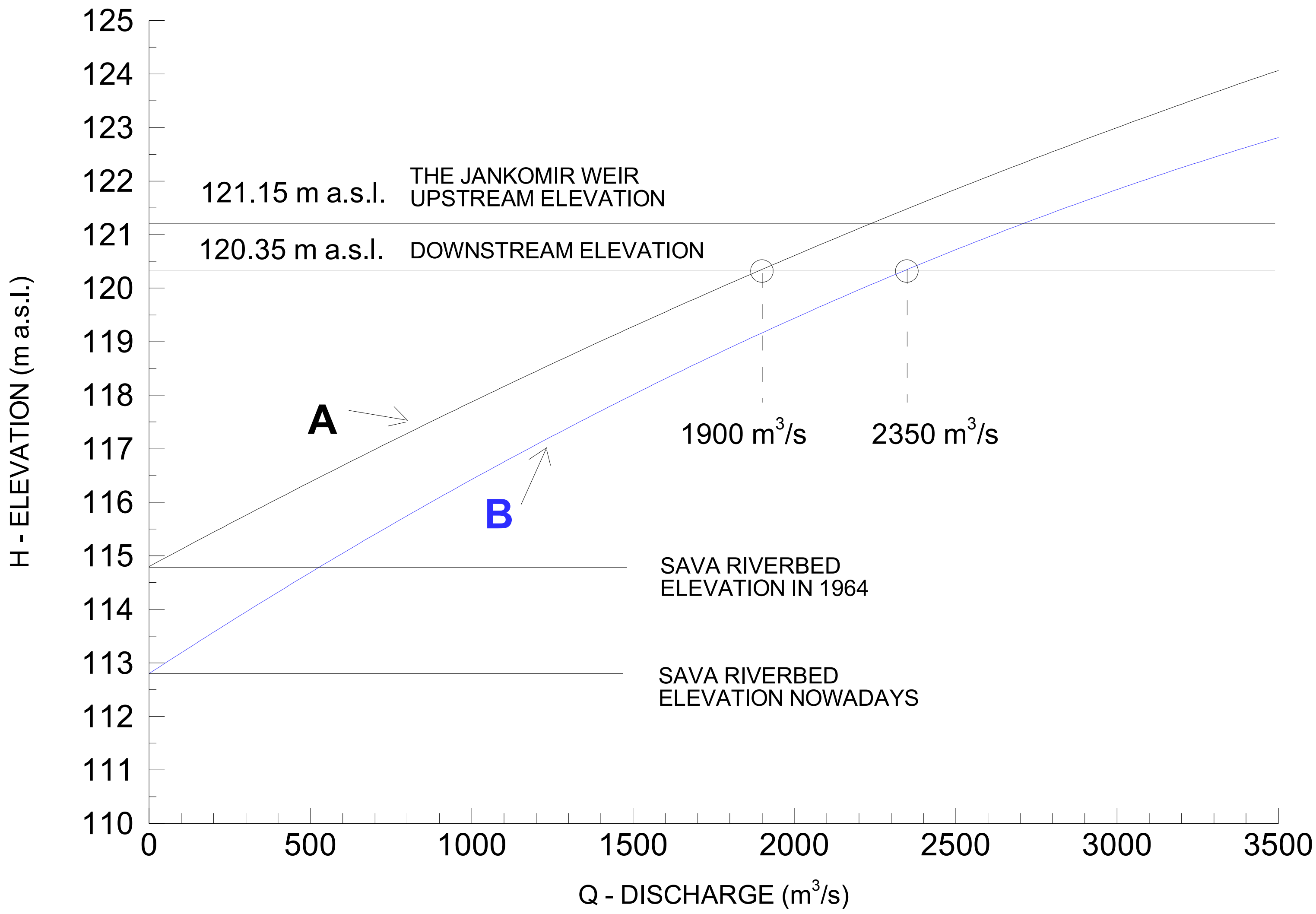

Figure 2 Stage-discharge curves for the Sava River profile on river km 711 in 1964 year (A) and nowadays (B)

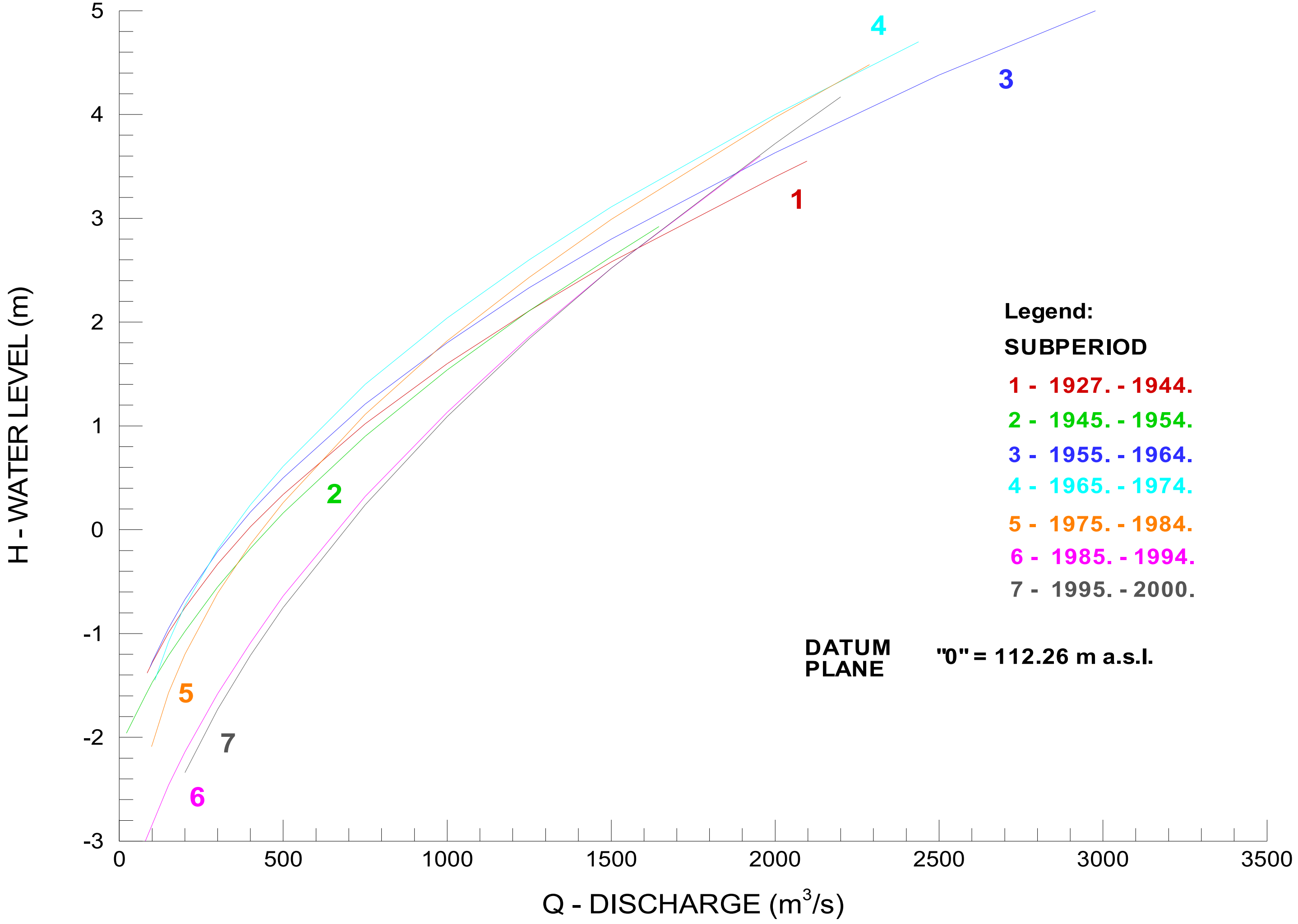

Figure 3 Stage-discharge curves for seven subperiods defined at the Sava Zagreb gauging station

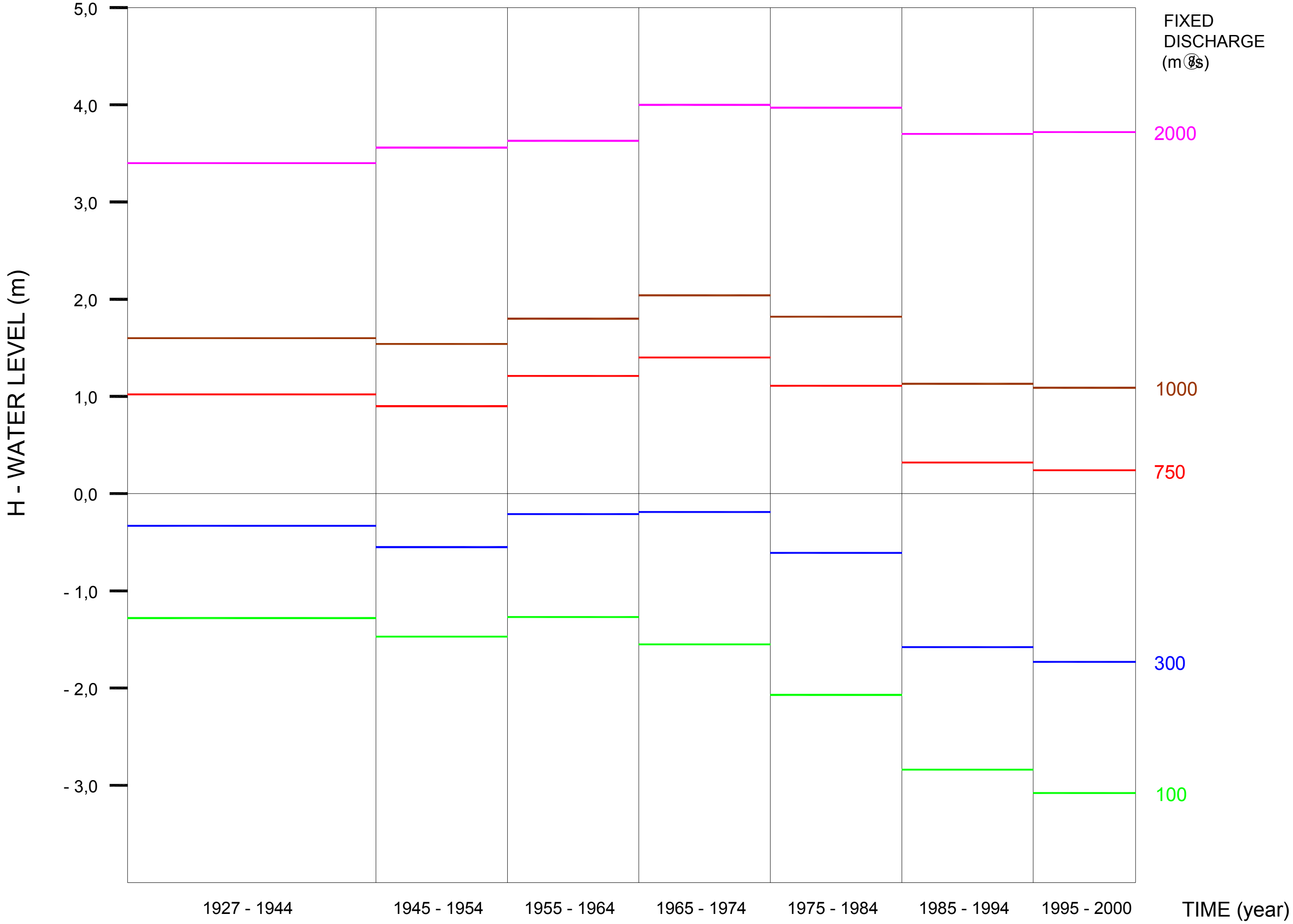

Figure 4 Changes of water level (stage) over time at the Sava Zagreb gauging station defined using seven stage-discharge curves given on the Figure 3

For prevention of the Zagreb town from floods complex flood control system was designed and constructed. The main parts of this system are: 1) New higher and stronger river embankments ; 2) Broadcrested weir Jankomir 1000 m long; 3) Relief canal Sava-Odra (Fig. 1). This system was finished at the end of 1978 and the Jankomir weir firstly was in function during 1979. The Sava-Odra relief canal is 51,4 km long nad its maximum capacity is more than 1500 m^3/s. The Jankomir weir is activated automatically. Figure 2 shows two stage-discharge curves for the Sava River profile immediately upstream of the Jankomir weir in 1964 year and nowadays. Recent elevation of the Sava riverbed is about 2 m lower than 40 years ago. The spillway is in function when discharge of the Sava River is about 2350 m^3/s. It should be noticed that it was designed that the Jankomir weir starts with work when discharge reachs value of 1900 m^3/s.

Obviously new hydrological conditions prevail in the analysed area. In this paper assessment of the Zagreb town flood defance in new conditions will be given. The main caracteristics of any flood are its maximum water level and maximum discharge. Both of them willl be used to assess changes in safety of the Zagreb town flood defence. The analyses of series of maximum annual Sava River water levels and discharges measured at the gauging station Zagreb in 1926-2000 pariod will serve to perform this task.

Pinter et al. (2001) state that a river's flood response can change over time as a result of land use change, engineering modifications of the river channel or long-term climate change. Regardless of the cause, rapide hydrologic change requires that pre-existing assessments of flood frequency, recurrence times, predicted flood levels and flood plain zonations must be updated periodically to reflect current conditions.

Normalization or actualisation of maximum annual water levels time series

On the gauging station Zagreb at the Sava River 292 discharge measurements exist during the 1926 to 2000 period. Figure 3 shows seven stage-discharge curves defined for next subperiods: 1) 1926-1944; 2) 1945-1954; 3) 1955-1964; 4) 1965-1974; 5) 1975-1984; 6) 1985-1994; 7) 1995-2000. In this paper a technique for normalizing historical hydrologic data to a last period (1995-2000) is used (Pinter et al. 2001). New normalized or corrected value of maximum annual water level in year j $H^*_{max\,j}$ is defined by next equation:

$$H^*_{max\,j} = H_{max\,j} \pm \Delta H_j$$

where $H_{max\,j}$ is measured value in year j while ΔH_j is correction defined using Figure 4. On this Figure changes of water level over time at the Sava-Zagreb gauging station are presented. Each cluster of lines indicates stages associated with a fixed discharge. That changes in stage over time indicate changes in the conveyance capacity of this profile or section of the river. In Table 1 values of measured (uncorrected) and corrected (normalized) maximum annual water levels for different recurrence periods using log normal distribution are given.

Table 1 Numerical values of measured and corrected maximum annual water levels for different recurrence periods defined by log-normal distribution curves

RECURRENCE PERIOD (year)	WATER LEVEL (cm)		H* - H (cm)
	MEASURED H	CORRECTED H*	
1000	632	771	138
100	528	607	79
50	495	557	62
10	413	438	25
5	372	381	9
3.33	345	345	0
2	305	293	- 12

Analyses of time series in two subperiods

Maximum annual water levels and discharges are analysed in two subperiods. In the first subperiod from 1926 to 1978 the Jankomir weir was not in function while in 1979–2000 period it was in function.

Table 2 gives the values of maximum annual water levels and discharges in two above mentioned subperiods defined using log-normal distribution. Both flood characteristics are lower for the same recurrence interval in the last subperiod from 1979-2000.

Table 2 Numerical values of maximum annual water levels and discharges for different recurrence periods defined by log normal distribution curves

RECURRENCE PERIOD (year)	MAXIMUM ANNUAL WATER LEVEL			MAXIMUM ANNUAL DISCHARGE		
	SUBPERIOD		ΔH (cm)	SUBPERIOD		ΔQ (m^3/s)
	1926-1978	1979-2000		1926-1978	1979-2000	
1000	647	600	47	3955	3309	646
100	540	498	42	3235	2780	455
50	506	466	40	3012	2613	399
10	422	385	37	2458	2191	267
5	380	346	34	2190	1982	208
3.33	352	320	32	2014	1844	170
2	311	281	30	1755	1636	119

Conclusion

Definite conclusion is that in new conditions the Zagreb town is better protected from the Sava River floods. Main reason for this is functioning of the Jankomir weir and Sava-Odra relief canal.

References

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