

Forecast of Changes Concerning the Water Budget in a Wetland of Danube Floodplain

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Abstract: The water budget of the examined wetland was extremely variable in the past six years. Principally, it was affected by the water regime of the River Danube and the climatic factors. In order to investigate the changes of these elements, and to succeed to forecast, statistical methods by using SPSS program were performed. The time series of the evaporation, of the precipitation and of the river's water-level were analysed by linear regression, by exponential smoothing, by deterministic models. In consequence of the river regulation, the low-water and the mean stage of Danube were decreasing during the last hundred years, because the riverbed was permanently deepening. Since the river has overflowed its bed and has inundated to the wide floodplain, the decrease of high-water did not appear. The decline of the flooded days signed the quicker passage of flood. These processes have prevented that the examined wetland is going to fill up from the floods. The difference in summer semester between the evaporation and the precipitation was increasing during the last fifty years. Therefore, the drying out of the wetland is going to be more frequent in the future. In the interests of the survival of this wetland, it is necessary to construct the restoring-system in the floodplain.

Key words: Wetlands, climatic factors, nature conservation treatment, water regime.

1. Introduction

A quarter of the whole present-day territory of Hungary was floodplain until the 19th century, when the works of river regulation have started. Nowadays, 97 per cent of this region is protected against floods [1]. The Hungarian floodplains stand for internationally significant values concerning the landscape and the nature conservation, because the land has kept its original facade and living world in spite of regulation works [2]. Gemenc is a conservation wetland area, which is situated in the Lower Danube basin of Hungary. In the early seventies of the 20th century there were foresters who have attracted attention for the drying process occurred in the vegetation of the forests in Gemenc [3]. It was found that the reason for this

process is the deepening of riverbed in consequence of the river regulation [1].

Regular hydrological observation and measurement started in the beginning of the 20th century in Hungary. Nowadays there are water level records available for more than 100 years, and discharge records for 80-90 years for many station on the Danube [4]. The linear trend analysis of these records showed that the annual extremes (minima and maxima) and averages of water levels indicated a significant falling trend, but this trend cannot be found in the records of the discharges.

The water level of Danube has decreased, as the riverbed has deepened since the river regulation. This process led to isolation, siltation and the ever more stable drying up of the wetlands in the floodplain [1]. Among the floodplain wetland areas of Gemenc, it was the "Nyéki-Holt-Duna" on which the water circulation revitalisation was first carried out between 1998 and 2004 [5].

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The Nyéki-Holt-Duna, a former river-bend, now is an oxbow lake [6], which was cut off in a naturally way three hundred years ago [5]. Because of its declining water budget, it has dried out several times until the seventies of the 20th century therefore, its natural values and its role in the stabilization of water table have been endangered [1]. The yearly filling up could have been proved by the way of water-circulation revitalization, so that the following water losses could not cause a full desiccation. To ensure the water retaining, sluices and bottom-dams were planned to construct, and in the interest of easier water-supplement, dredging of channels were also projected. However, the state of the wetland could not be completely restored, it is henceforward frequently drying out [5].

The hydro-chemical and hydro-biological results [5] showed that the water quality of oxbow lake is related to the water budget. During the term of floods, it depends on the quality of water flowing from the Danube, while during the term of floodless periods it depends on the vegetation. In floodless periods, because of the low water-level, one or perhaps more chemical parameters became risky, which parameters were indicated by the organism sensitive for these materials. The following floods have brought favourable changes regarding the chemical quality. The ecological requirements of vegetation are similar to those ones that were discovered by ornithological monitoring [7, 8]. The most favourable states were the floodless periods, when a slow diminution occurred after the fill-up in early spring. Those years, which have brought an almost dried-out oxbow-bed, were similarly as unfavourable as the multiple floods with a high level of water during one vegetation period. In order to observe the favourable conditions of this habitat, the states of water budget qualified unfavourable are by all means to avoid, therefore further technological interventions are necessary in the field [5]. When planning these interventions it is indispensable to consider the changes of climate, just like the changes of the water regime in Danube, which

appear in consequence of the interventions in the catchment area of river.

Nowadays climate change causes future efforts to restore and manage wetlands in detail, and it has become important to recognize that specific plans will require examination by these habitats. The wetlands are very different habitats, with different factors and hence different management and restoration techniques are needed [9].

In this paper, we are studying the changes of the water budget of the Nyéki-Holt-Duna after the rehabilitation. The balance of the water budget were analysing in 2003, which year was qualified ecological favourable. By the help of statistical analyses of the Danubian water levels and the climatic factors, we are predicting the procedures acting unfavourably on water circulation, and we are recommending a proposition of intervention in order to compensate these processes.

The Kolmogorov-Smirnov non parametric test and the linear regression are the current method for the trend analysis of the water levels in Hungarian part of Danube [1, 4]. Notwithstanding that many different statistical methods and models have been used in the international hydrological studies. The Autoregressive Integrated Moving Average Models (ARIMA), which constructed employing the Box-Jenkins method [10], is particularly useful in hydrology, mainly for the prediction of water level [11-14], and the simulation of climatic periods [15]. We adopted the motions, found in these articles, to choose the statistical methods and models for the analysis of different hydrological factors.

2. Materials and Methods

2.1 Study Area

The Nyéki-Holt-Duna is located on the floodplain of the Danube, therefore its water balance mostly depends on the water regime of the river. The floodplain wetland does not have considerable catchment area because of the relief-relations, therefore its aboveground water-supplement is only possible by the

means of transmitting the elements belonging to its water system (Fig. 1) or by the water flowing from the Danube streaming across the ambient forests. In the surroundings of the Nyéki-Holt-Duna the suffusion of the floodplain starts at 87.5 meters above the Baltic, which is parallel to the 650 centimetres measured on the water-gauge in Baja.

In order to fill up the oxbow lake, it is necessary to have a suffusion of 10-12 days, because of the flood wave's sagging on the wide floodplain of Gemenc. Due to the restoration investments, the oxbow-bed could not only receive water from the overflows, but also by its water-system when the water level of the Danube is 85.8 meters above the Baltic (it is 490 centimetres on the water-gauge of Baja) (Fig. 2).

2.2 Examination of the Water Budget

On the score of the water level's changes observed in the vegetation periods, we have determined the oxbow lake's type of water circulation typical in the given

year. By our geodesic survey's items, we have designed a bed-map using AUTOCAD, and we have constructed a surface-volume graph. By these surveys, we have counted the lake-volume belonging to different water levels.

In the course of the hydrological monitoring constructed in the Nyéki-Holt-Duna, the recording of the falls and the changes of water level were made between 1st of March and the 30th of September in 2003. We have measured the loss of water in this oxbow lake concerning this period, by measuring the lake-volume in initial and terminal water levels. In order to identify other factors that could influence the water balance (for example the leakage), we have compared this survey with the distinction of precipitation and weighted losses by evaporation, calculated on the average surface of the lake. Because during the hydrological monitoring, there were not made any survey relevantly the evaporation of the aboveboard water-surface and the vaporization of the

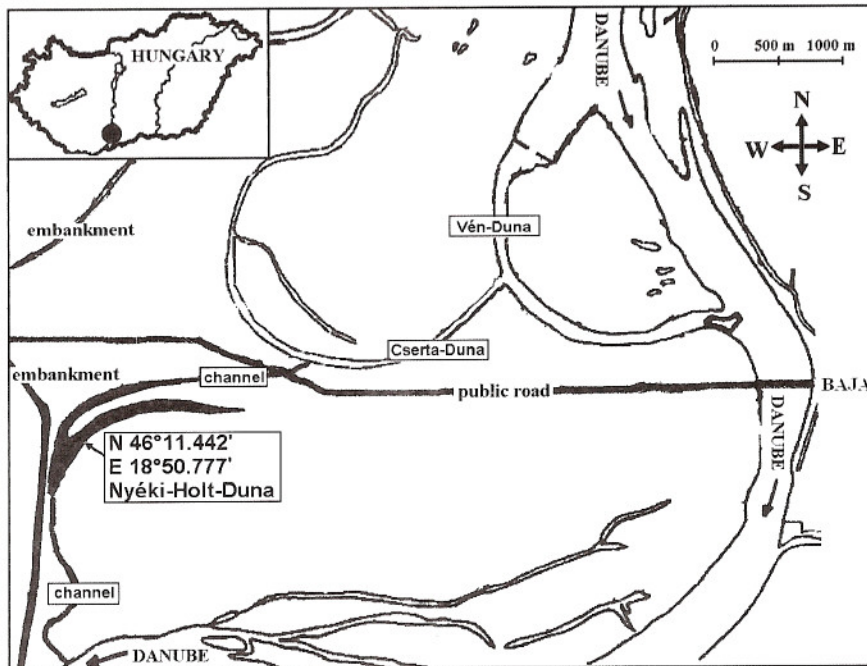


Fig. 1 Situation of Nyéki-Holt-Duna and her water-system.

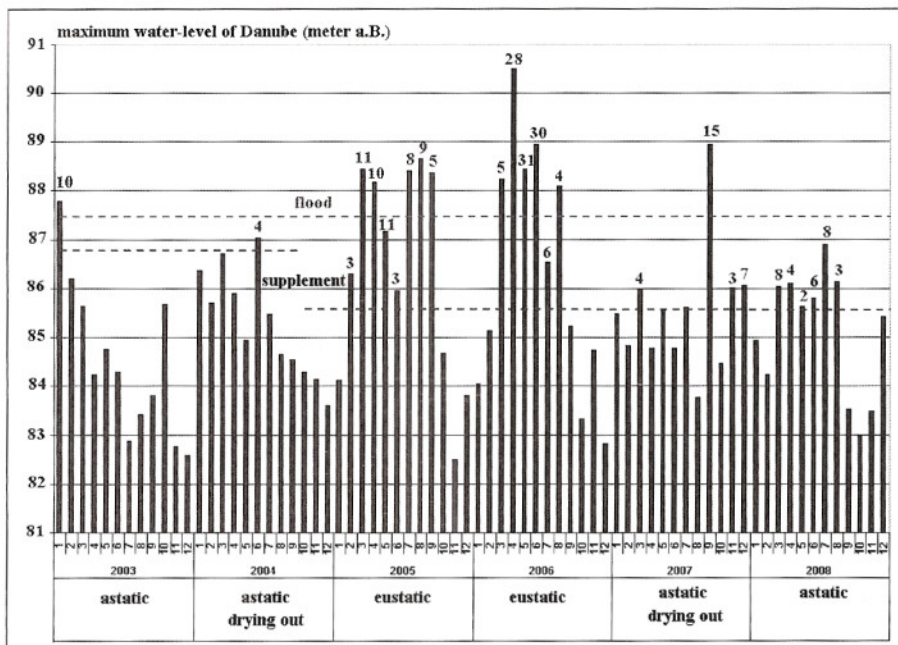


Fig. 2 The water level of Danube and its effects (flood/supplement) for the water-regime (astatic/eustatic) of the Nyéki-Holt-Duna.

plant-life. To measure the evaporation of the water-surface covered by vegetation, we have respected for the items of standard evaporation, for the vaporization constant of reeds determined to the Hungarian lakes, and for the monthly conformation of the plan-life coverage.

2.3 Statistical Analysis of Hydrological Data

Analysis have been made on the data line of precipitation (1901-2005) and evaporation (1950-2006) measured by the hydro-meteorological state in Baja, in order to predict the future conformation of these items. We have counted the drought index by Pálfai [16] in order to identification of years overtaken by climatic drought. To be acquainted with the changes occurred and predicted in the water regime of the Danube, we have estimated the data line recorded on the water-gauge in Baja since 1901, by using the means of statistical analysis. To analyze the tendency and the effects of season, and to perform the forecasts, we have used SPSS 14.0 statistical programs. In favour of trend

analyzing along with the conventionally linear regression, we have made the best of using Additive and Multiplicative Deterministic, Exponential Smoothing Simple, Exponential Smoothing Holt, and ARIMA-models. We checked the statistical authenticity of models using Kolmogorov-Smirnov method, trying to find out, whether residuals are normally distributed. Since the 'Normality of Residuals' (RNORM) is greater than 0.05, the check for the model is fulfilled. The results have been compared, to predict the changes we have accepted the most adaptable models to different hydrological factors, which have given the least 'Residual Sum of Squares' (RSS).

The time series in the deterministic model should take as the sum (additive model) or the product (multiplicative model) of an occasional component and three deterministic components (trend, seasonal fluctuation, cycle). The smoothing processes preferably consider the occasional character and the internal connection of time series than the deterministic

models. They try to decrease the effect of coincidence by average therefore they emphasize the deterministic character. The most shaded and complex analysis is possible in ARIMA-models, which presumes internal stochastic coherence between data of time series. This coherence is persistent, detectable and probably will also present in future procession. In these models the time series is considered as the sum of an autoregressive (AR), of a moving-average (MA) and of a non-correlated component [17].

Seasonal decomposition was made on the monthly with the water level data of the last ten years of Danube with additive and multiplicative deterministic models using SPSS. The representation of trend components, have made using exponential smoothing on deprived time series of the seasonal tag, provided to examine the change of water level within the given year. We performed normality test with Kolmogorov-Smirnov method on the residuals, and concluded from achievement of decomposition.

We examined the annual water level data and the annual precipitation and evaporation of summer semester of Danube with exponential smoothing method using SPSS. The program accomplished iterations and determined the parameter that the error of model (RSS) will be the least with. In the Exponential Smoothing Simple Model there is no trend, the Exponential Smoothing Holt Model supposes a linear trend.

The Autoregressive Integrated Moving Average Models are denoted by the notation ARIMA (p, d, q), where 'p' is the degree of autoregressive part, 'd' is the degree of differencing, 'q' is the degree of moving average process. The ARIMA model building strategy includes iterative identification, estimation, diagnosis, and forecasting stages. By the identification stage we applied the Kolmogorov-Smirnov Z-test and the Mann-Whitney U-test (used SPSS) to examine the existence of trends (Table 1). To determine whether there is a trend according to which the calculated statistics (U_c and Z_c) should be compared to the critical value of normally distributed Z-table. If the statistic

lies within the 5% significance interval ($-1.96 < Z < 1.96$), there is no trend for the data set. The two-tailed asymptotic significant has been counted automatically by SPSS (Table 1). In accordance with autocorrelation function and partial autocorrelation function, which were drawn by SPSS, we could decide what ARIMA-process should be used. In the estimation stage we needed to use a few model parameters so that the model could fulfil all the diagnostic checks. The diagnostic check stage determines whether residuals are independent, homoscedastic and normally distributed [14]. We applied the residual autocorrelation function, which was drawn in the correlogram by SPSS and we examined the RSS (Residual Sum of Squares) and SBC (Schwarz's Bayesian Criterion) statistics of models. In the forecasting stages we prepared prediction until 2050 by using the most suitable model, of which was the least RSS and SBC.

3. Results and Discussion

Between 2003 and 2008, when we have made our examinations, the rehabilitation ambition, namely the yearly filling up of the oxbow lake, was only partially realised. The years 2005 and 2006 have brought overflowed periods several times (Fig. 2). Apart from these years, the months January in 2003 and September in 2007 has resulted floods. However, in 2004 and 2008 the floods have fallen off. It follows that in the years 2004, 2007 and 2008 the oxbow lake was not able to fill up until the start of the vegetation period. In case of the Danube's low water level, considering the vegetation period, the water-supplement coming across the water system has only developed in 2008.

By the duality of the water circulation, the Nyéki-Holt-Duna is classifiable into the group of semistatic waters. Its idiosyncrasies are the absence of poise, the changes moving in a relatively wide range, and in an uncoordinated time, sometimes during one period of vegetation, but acting upon the Danube's regime. Therefore it can be qualified sometimes eustatic and at other times astatic.

Table 1 Examination the existence of trends with non parametric test.

		Mann-Whitney test		Kolmogorov-Smirnov test	
		U_c	asympt. sig. 2-tailed	Z_c	asympt. sig. 2-tailed
Danubian water level	annual maximum	1.190	0.234	0.924	0.360
	annual mean	3.197	0.001	1.513	0.021
	annual minimum	3.550	0.000	2.051	0.000
Evaporation of summer semester		3.799	0.000	2.194	0.000
Precipitation of summer semester		0.766	0.444	0.721	0.676

Due to the high water level of the Danube occurring in January 2003, the oxbow-bed has filled up. However, during the year the supply of water has only come from the rainfall. Therefore, its water level has shown a slow shrinkage until autumn. Until the end of September, the deepness of water has decreased to 10 per cent of the primary water level. The shallower upper arm has completely dried out. Water has remained only in marks in the common arms, and in a narrow continuous stripe on the central line of the deeper lower arm. Due to the data read on the surface-volume graph (Fig. 3), the volume of the oxbow lake has reduced to 1 per cent, and the surface has decreased to 8 per cent, which means 364 thousand m^3 of water-loss. However, the calculation resulted only 169 thousand m^3 of water-loss. There are two reasons to show this difference. For the first time, the low-rated leakage determined by the examinations of soil research, on the other hand, the adaptability of the reed-constant.

The determinative part of the oxbow lake is covered by pondweed vegetation, also the surface of the water is covered by plants with large-sized leaves [5]. Therefore, the vaporization of these plants transcends the rates of the reed. Furthermore, in case of aboveboard surface of water, due to darken colour because of the high quantity of organic materials, and the more powerful warming up due to the pondweed situated in low deepness, the rate of vaporization-loss could be higher than in a standard evaporation-bath. In the interest of unequivocally verify or exclude the leakage of the bed, the only method is to use analyses after measuring the evaporation of free and of plant-covered water surfaces.

In 2003 the hydrological relations have formed an ecological favourable water-balance, in spite the moderate climatic drought. However, as long as the leeway of swellings in vegetation periods coincides with the grave climatic drought, the total drying up of the oxbow lake will occur. As soon as happened in 1992 (Fig. 4), when the very grave drought coincided with the permanently low water-level of Danube. It can also lead to drying up in the immediate future, when through climatic changes, the difference between the precipitation and the evaporation of summer semester furthermore increases. All of the models (Table 2) used to analyse the data of precipitation and evaporation of the last 60 years (Fig. 5), have signed the continuous increasing of differences. The dispersion of precipitation data is normally (Table 1), there is no noticeable long term change, just a fluctuation around the average (345 mm). On the other hand the evaporation of summer semester was on powerful increase. Therefore, in the immediate future it will more frequently occur that the filling up of the oxbow lake from spring swellings will not be sufficient to compensate the latter water losses.

In the last 100 years a remarkable change has occurred in the frequency of flood-suffusions and in the number of days which have brought suffusion (Fig. 6). Until the 1950, years without floods have come back in 10 years periods, while after 1950 this period was an average of 3 years. Also, the number of overflowing days has decreased to less than its half. Therefore, the changes occurred in the water regime of the Danube would result water deficit of the oxbow lake.

The remarkable decreasing of water-level (1.5 metres) predicted to 2010 by the water-level-statistic analyses with linear regression [1] has just partially

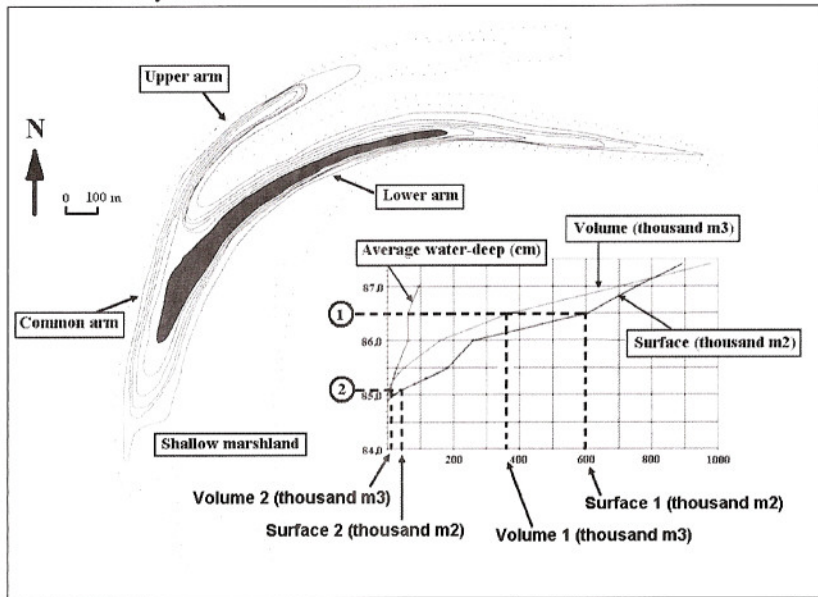


Fig. 3 The scene-sketch with contour line of Nyéki-Holt-Duna, and its volume-surface graph. 1: start of examination in 1st March 2003, 2: end of examination in 30th September 2003.

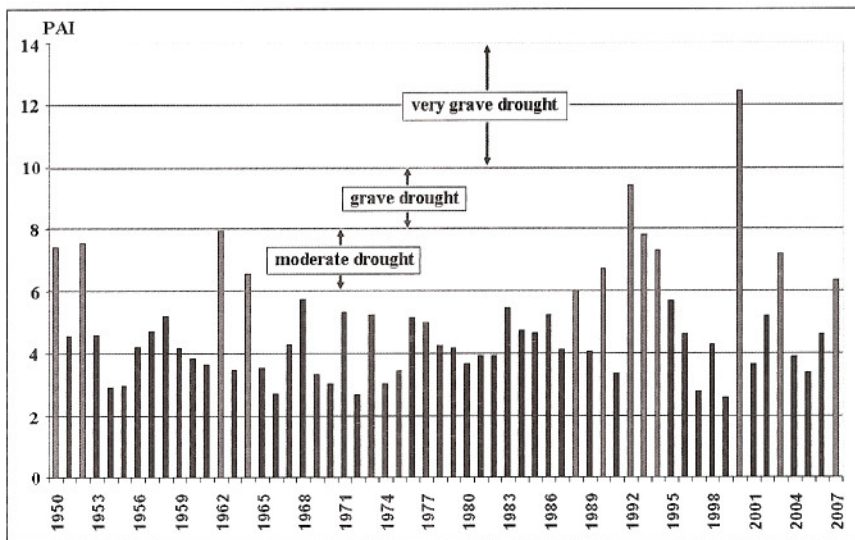


Fig. 4 Identifying the drought years using the drought index by Ref. [16].

eventuated in recent years [4]. In point of the yearly maximal water-level (Fig. 7) there is no statistically acceptable long term change [1, 4] just a fluctuation

around the average (739 cm). The reason of this tendency is that, while the low and average waters

stream in the deepening riverbed, until then the high waters march off by seceding to the floodplain, and in the latter case the riverbed erosion does not play a significant role.

The different models (Table 3), used to forecast the Table 2 Analysis of climatic data (RSS: Residual Sum of Squares, RNorm: Normality of Residuals using Kolmogorov-Smirnov test).

Data	Models	Statistics of models	
		RSS	RNorm
Evaporation of summer semester	Linear regression	816,469	0.817
	Exponential	595,767	0.379
	Smoothing Simple		
	Exponential		
	Smoothing Holt	590,656	0.431
ARIMA (1.1.1)	584,107	0.830	
Precipitation of summer semester	Linear regression	844,089	0.405
	Exponential	817,449	0.324

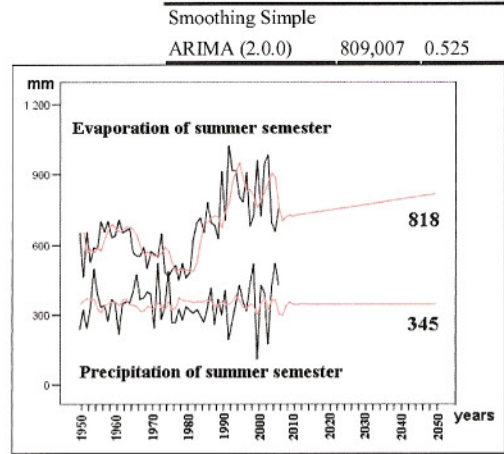


Fig. 5 Analysis of climatic data and forecast from 1950 to 2050.

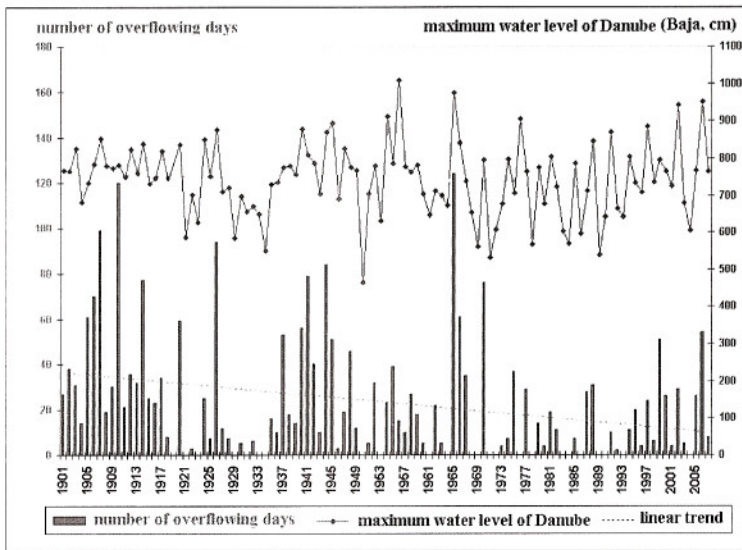


Fig. 6 Changes in the water regime of Danube.

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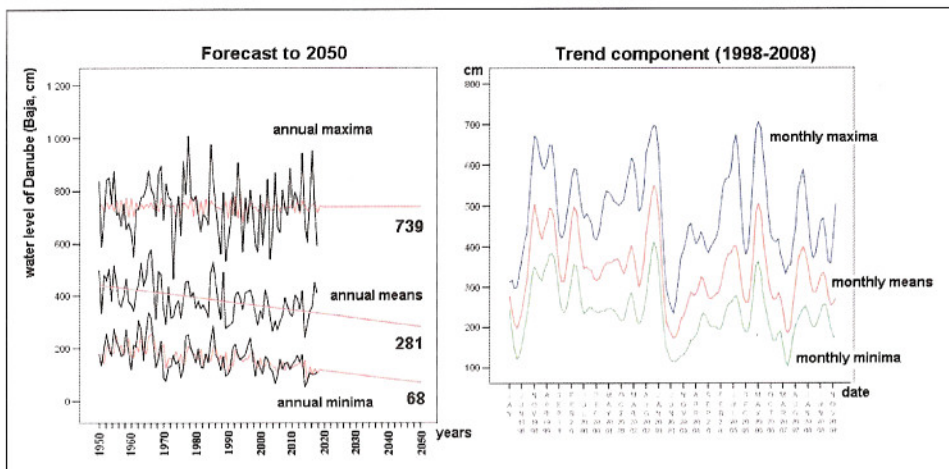


Fig. 7 Analysis of the Danubian water regime and forecast to 2050.

Table 3 Analysis of the Danubian water regime (RSS: Residual Sum of Squares, RNorm: Normality of Residuals using Kolmogorov-Smirnov test).

Data	Models	Statistics of models	
		RSS	RNorm
Annual maxima	Linear regression	1,005,824	0.997
	Exponential	1,010,088	0.995
	Smoothing Simple		
	ARIMA (1.0.2)	980,162	0.909
Annual means	Linear regression	388,624	0.762
	Exponential	422,906	0.750
	Smoothing Simple		
	Exponential	420,141	0.976
	Smoothing Holt	417,832	0.974
Annual minima	Linear regression	234,358	0.774
	Exponential	250,502	0.959
	Smoothing Simple		
	Exponential	248,963	0.928
	Smoothing Holt	208,338	0.749
	ARIMA (2.1.2)		

statically prospective changes of water-level in the immediate future, show different processes. The statically expected high stage waters will shape according to the hundred-year average. However their flowing will be faster, due to the decreasing number of flood-days. These processes could prevent the oxbow lake filling up from floods.

A remarkable decrease of water level is expected in point of low and mean stage waters. The rate of this

decrease, estimated by statistical methods, will be around 1 meter below the hundred-year average, in 2050, in case of both parameters (Fig. 7). This change will arrest the water support of the oxbow bed, beyond the floods (the threshold water-level is 490 cm). We can produce the better fitting at the data-line of middle-stage waters by using linear regression, which is related to the derivative aspect of the data-line.

The early spring and the late summer high-waters are representative to the seasonal character of the water-regime in Danube. The analyse of the monthly water-stage series deprived from seasonal effects shows 4-5 years periods (Fig. 7), in all of three characters. In such spaces of times are the low water-stages expected.

Those years which have brought several suffusions have just reported in three year periods concerning the last 50 years. Therefore, the conservation is not obligated to handle the problem of persistent water-coverage unfavourable for the oxbow-bed.

4. Conclusions

The water balance of the wetland situated in the floodplain of the Hungarian Lower-Danube valley has shaped extremely in the face of water circulation

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corrective interventions. The years 2005 and 2006 have brought overflowed periods several times. In the years 2004 and 2007 the oxbow bed has dried up. The favourable surroundings of natural habitat have just shaped in 2003 and 2008. The drying up respected to the complete bed, and also the persistent suffusion are to avoid in order maintaining the character of the habitat.

In the changes of the water balance of the oxbow lake, the climate and the water regime of the Danube play the most important role. The leeway from the bed is small-rated, but it could not be completely excluded. The plant-life covering most of the bed can significantly influence the evapo-transpiration. To appreciate the evaporation of wetland, the vaporization constant of reed practiced in Hungary is not suitable.

The climatic water-shortage has been considerably rising in the past 60 years. The increasing difference between the evaporation and precipitation of the summer semester will cause problems in the immediate future, in those years when there will be no suffusion or will be just in early spring. In these times the complete drying up of the bed is expected.

On account of the interventions made in river regulation and in the catchment area, the water circulation of the Danube has changed. While the low and middle stage waters run off in the deepening riverbed, a decrease has occurred in the past 100 years in point of the yearly minimum and average water-levels. In case of both characters, the decrease of water-level, estimated until 2050 by statistical methods, is expected at about one metre below the hundred-years-average. While the high waters run off by seceding to the floodplain, remarkable decrease of water-level has not developed in point of yearly maximal water-levels. However, in the past 100 years the number of flood-days and the frequency of suffusions have significantly decreased. All of these results will eventuate the more frequent drying up of the oxbow bed in the immediate future. To avoid this, further interventions are necessary.

In order to compensate the conformation of unfavourable surroundings of natural habitat, the wetland bed is to share artificial water-support. It will be necessary in case of leeway of spring floods and in droughty periods of summer. In view of the changes in the water regime of the Danube, it is suggested to construct a storing on the floodplain such appropriate solution. A reservoir-system is to artificially construct in lowly areas of the surroundings of the Nyéki-Holt-Duna. It should be connected to the upper channel (Fig. 1), which provides the water-support of the oxbow lake at also the present time, to maintain the original direction of the water-support also in low-water periods. In order to faster filling up, the connection between the Danube and the reservoir-system is to be solved by more subordinate channels. The reservoir-system could simultaneously operate as habitat of waterfowls.

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