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DEVELOPMENT OF GROUNDWATER LEVELS AS A CONSEQUENSE OF CLIMATE CHANGE

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ABSTRACT

Climate change poses a significant threat to many wetland ecosystems. Wetlands exist in a transition zone between aquatic and terrestrial environments and can be affected by slight alterations in regional hydrology, which can influence climate change through air temperature changes, regional changes in a rainfall regime, surface run-off, snow, duration of the winter season, groundwater resources and evapotranspiration.

Climate change in wetland areas is most significantly reflected in water levels and adjacent groundwater levels, and it can significantly change the hydroecological proportions of wetland ecosystems and endanger rare wetland fauna and flora communities. The focus of this paper is the impact of climate change on the groundwater level in the Záhorie Protected Landscape area in the Zelienka national nature reservation. The impact of the climate change was solved through the meteorological characteristic changes adapted by the GISS98 and CCCM2000 climatic scenarios. The groundwater level was determined by the HYDRUS-ET model for the time frames 2010, 2030 and 2075 in 20-year time intervals and consequently compared to the reference period of 1971-1990.

KEY WORDS

- *climate change,*
- *wetland,*
- *groundwater level*

1. INTRODUCTION

Climate changes occur due to internal changes in a climatic system but also due to outside influences which are natural factors (solar radiation, cloudiness, precipitation) and factors caused by human activity (increasing concentrations of greenhouse gases) in the atmosphere. Ongoing climate change and its consequences nowadays represent one of the most serious global problems (IPCC, 1998, 2001).

Climate change poses a significant threat to many wetlands. The most significant can be the climate change reflected in changes in the groundwater level (GWL); as a consequence, changes in hydroecological conditions can occur, and rare wetland vegetation can be endangered.

The focus of this paper is an evaluation of the development of GWL as a consequence of ongoing climatic changes in a specific wetland in the Záhorie Protected Landscape area in the Zelienka national nature reservation. The impact of the climate change was solved through changes in meteorological characteristics reconditioned by the GISS98 and CCCM2000 climatic scenarios (the CGCM2 Canadian model was modified to fit Slovak conditions) (Lapin, et al., 2001).

The development of GWL was analysed with a mathematical simulation model, because it is the most suitable method for determining a soil water regime in the event that monitored data is not available. The main advantage is the relatively fast implementation (Nagy, Brezianska, 2010; Horváth, et al., 2007).

SLOVAK JOURNAL OF CIVIL ENGINEERING

2012/1 PAGES 29 — 34

To simulate the impact of climate change on the course of a GWL, the HYDRUS-ET model (Šimůnek, et al., 1997) was chosen, which allows for the simulation of GWL changes (Pavelková, 2010; Štekauerová, Nagy, 2011).

2. MATERIALS AND METHODS

To solve the problem of the development of GWL due to climate changes for the Zelienka wetland, data from General Circulation Models (GCMs) were used. The climate in these models is represented by climate elements. For this purpose, these elements were modified according to the two selected scenarios of climate change, i.e. CCCM2000-unglazed and GISS98 for Slovakia. The CCCM model was developed by the Canadian Centre for Climate Modelling and Analysis in Victoria and the GISS model by the Goddard Institute for Space Studies at NASA in the USA. A more detailed description of these models and their output is given in the works of Lapin, et al. (2001, 2004, 2005, 2006).
Scenarios of climate change for the area of interest were developed for the time horizons 2010, 2030 and 2075 in 20-year intervals centered in 2010, 2030 and 2075. After preparation of other necessary inputs, it was possible to make the simulations of the GWL with modified values.
To simulate the impact of climate change on the course of a GWL, the HYDRUS-ET model was chosen. At first, the HYDRUS-ET model was verified using data measured from the years 2001 and 2002. It compared the measured GWL in a probe of the area of the Zelienka wetland with simulated GWL. From the visual comparison it can be seen that the calculated GWL approximately follows the course of the measured GWL (Figure 1). For a comparison of the measured and simulated GWL, regression analysis was also used. The correlation coefficient R = 0.93 shows the very close relationship between the assessment elements. On this basis, it can be concluded that the HYDRUS-ET model is suitable for forecasting the course of GWL in the Zelienka wetland.

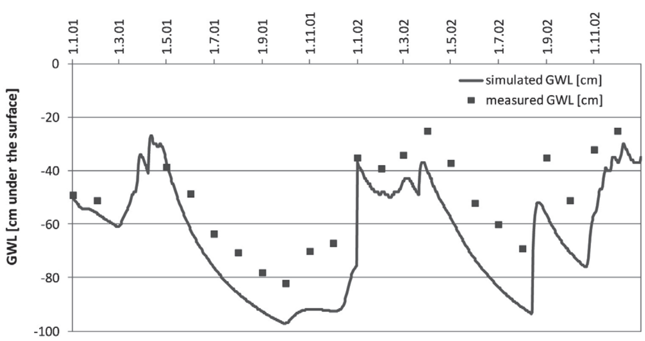

Fig. 1 *Course of measured and simulated GWL for the years 2001 and 2002.*

Following the outputs from the HYDRUS-ET model, an analysis of the impact of climate change on the course of the GWL using the above-mentioned climatic elements, which were modified by the two CCCM2000 and GISS98 scenarios of climate change for the time horizons 2010, 2030 and 2075 as well as for the reference period 1971 – 1990, was made.

2.1. MODEL INPUT DATA

To describe modelling the processes in the soil and get the appropriate results, we need to have well-prepared input data. The soil characteristics, meteorological data, crop parameters and initial conditions belong among these input data.
The soils in the model are characterized by a water retention curve (WRC) and saturated hydraulic conductivity. For this purpose undisturbed soil samples from two locations were taken. The first location was placed in the middle of the wetland, near the GWL probe, and where sample Nos. 4, 5 and 6 were taken. The second location was placed near a watershed divide, where sample Nos. 1, 2 and 3 were taken. The samples were taken at a depth of 30 cm. Laboratory analyses were performed, and the soil profile was characterized as homogeneous. The drying branch points were calculated with the use of pedotransfer functions (Skalová, 2001). The background for these functions was taken from the results of a particle size analysis performed using the densimetric method. These points were approximated according to Van Genuchten (1980), and the alpha and n parameters (the input to the model) were determined. The soil characteristics used in the modelling are summarized specifically for soil sample No. 6 in Table 1.
The meteorological data entered into the modelling included the daily rainfall total Z [mm], daily air temperature average T [°C], daily total of sunshine duration S [h], daily average of partial water vapour pressure p [hPa] and average daily wind speed v_v [m.s^{-1}] for each day of the period modelled. The meteorological data were from the observation station of the Slovak Hydrometeorological Institute (SHI) Malacky.
The parameters of the vegetation were derived from the vegetation cover, which is mostly part of the Zelienka wetland area. It is

Tab. 1 *Summary of the hydrophysical characteristics of a simulated soil profile (θ_s – water saturated soil moisture, θ_r – residual moisture, K – saturated hydraulic conductivity, α, n – Van Genuchten parameters WRC).*

Sampling depth [cm]	θ_s [cm^3.cm^{-3}]	θ_r [cm^3.cm^{-3}]	*K* [cm.d^{-1}]	*α* [cm^{-1}]	*n*
30	0.447	0.023	60	0.1869	1.2006

SLOVAK JOURNAL
OF
CIVIL ENGINEERING

2012/1 PAGES 29 — 34

represented by boggy alders as well as birch oak woods; the rest of the area is composed of pine woods. The parameters are located in an input file containing the leaf area index LAI [-], evaporation of the surface roughness z_o [-], the albedo of the evaporating surface α [-], the root zone depth z_r [cm], and the critical relative humidity [%].

The initial condition of the GWL on the first day of the simulation was entered into the HYDRUS-ET model. This value for the reference period 1971-1990 is 47 cm. For the time horizon 2010 the GWL in January 2001 – 49 cm was measured, and for the time horizon 2030 the GWL was calculated by the HYDRUS-ET model on 31/12/2020 – 88 cm under the surface.

The GWL at the area of the Zelienka wetland was measured for the period March 2000 – December 2003. The course of the measured GWL is shown in Figure 2, where a comparison is also shown for the monthly precipitation total from the SHI Kuchyňa - Nový Dvor observation station.

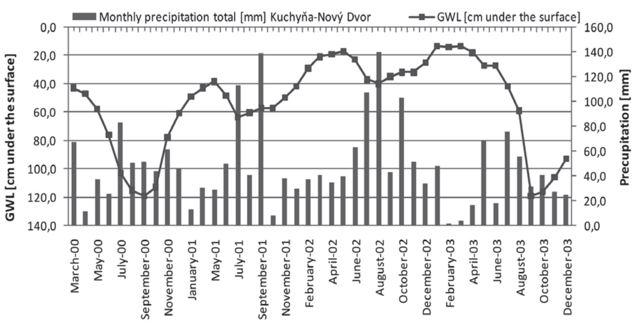

Fig. 2 *Course of measured groundwater levels (GWL) at the Zelienka wetland and course of monthly precipitation total measured at the Kuchyňa station for the period March 2000 – December 2003.*

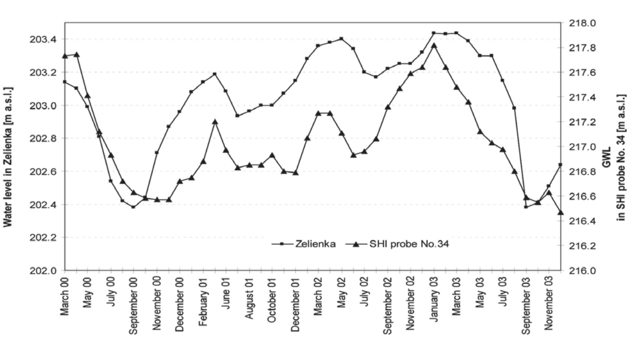

Fig. 3 *Course of the water level at the Zelienka wetland and the groundwater level (GWL) in the SHI probe No. 34 for the period March 2000 – December 2003.*

Whereas the GWL at the area of the Zelienka wetland was measured for the period March 2000 – December 2003, the initial condition of the GWL on the first day of the simulation was calculated using a linear regression for the reference period 1971-1990. The dependent variable was the GWL in the Zelienka wetland, and the independent variable was the GWL in SHI probe No. 34. SHI probe No. 34 is situated 2 km from the locality evaluated, and the GWL in this probe has been monitored since 1958. Figure 3 shows that the course of the GWL in the wetland corresponds to the course of the GWL in SHI probe No. 34.

3. RESULTS AND DISCUSSION

An analysis of the impact of climate change on the course of the GWL was made following the outputs from the HYDRUS-ET model. The output of the model was a time series of daily GWL that is difficult to compare. Therefore, the next calculated monthly and annual average values for the different GISS98 and CCCM2000 climate scenarios and the 2010, 2030 and 2075 time horizons as well as the reference period 1971-1990 were analysed.

In Table 2 there is a summary of the annual average values and their differences, following which we can analyse the relationship of the reference period and the GISS98 and CCCM2000 scenarios for particular time horizons and also the relationship of the particular time horizons of the selected scenarios and reference period.

Tab. 2 *Average groundwater level for the evaluated period [cm].*

Reference period 1971-1990	Scenario GISS98 for time horizon		Scenario CCCM2000 for time horizon	
76 cm	2010	81	2010	71
		-5		5
	2030	83	2030	74
		-7		2
	2075	81	2075	73
		-5		3

A comparison of the reference period 1971-1990 (groundwater level of 76 cm) with the CCCM2000 scenario for the time horizons 2010, 2030 and 2075 (Fig. 4) shows that there is an increase in the GWL in all the time horizons, which is 71 cm for the time horizon 2010, 74 cm for time horizon 2030 and 73 cm for time horizon 2075.

Figure 5 shows a comparison of the reference period 1971-1990 with the GISS98 scenario for the time horizons 2010, 2030 and 2075. It indicates that there is a slight decrease in the GWL from 76 cm to 81 cm for the time horizons 2010 and 2075 and to 85 cm for the time horizon 2030.

SLOVAK JOURNAL
OF
CIVIL ENGINEERING

2012/1 PAGES 29 — 34

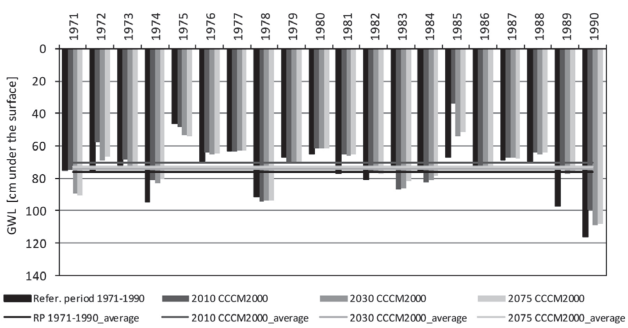

Fig. 4 *Course of the annual average groundwater level (GWL) in the Zelienka wetland calculated with the HYDRUS ET model for the 1971-1990 reference period and the CCCM2000 climate change scenario for the time horizons 2010, 2030, 2075.*

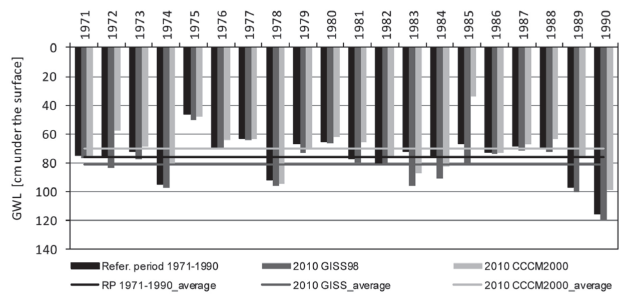

Fig. 6 *Course of the annual average groundwater level (GWL) in the Zelienka wetland calculated with the HYDRUS ET model for the 1971-1990 reference period and the GISS98 and CCCM2000 climate change scenarios for the time horizon 2010.*

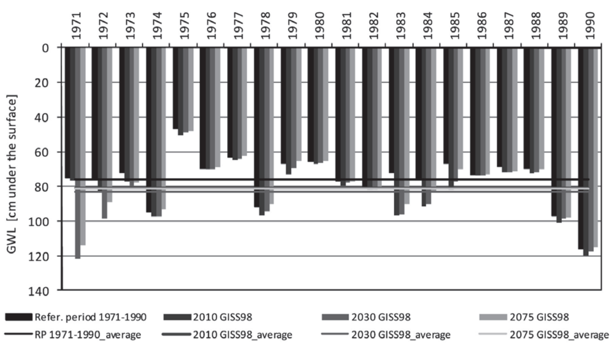

Fig. 5 *Course of the annual average groundwater level (GWL) in the Zelienka wetland calculated with the HYDRUS ET model for the 1971-1990 reference period and the GISS98 climate change scenario for the time horizons 2010, 2030, 2075.*

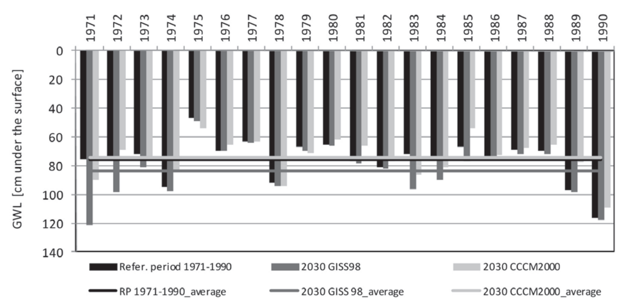

Fig. 7 *Course of the annual average groundwater level (GWL) in the Zelienka wetland calculated with the HYDRUS ET model for the 1971-1990 reference period and the GISS98 and CCCM2000 climate change scenarios for the time horizon 2030.*

Figures 6, 7 and 8 show the annual courses of the GWL according to the GISS98 and CCCM2000 scenarios for the particular time horizons 2010, 2030 and 2075 separately, when compared with the reference period 1971-1990. From these graphic outputs, it results that the course of the GWL according to the CCCM2000 scenario has an increasing trend in all the time horizons compared with the GISS98 scenario. The most significant is for the time horizon 2010, when the course of the GWL increased above 5 cm compared to the reference period.

Following the annual averages it can be concluded that the highest increase of the GWL was determined according to the CCCM2000 scenario for 2015 (in the case of the 2010 time horizon, it was the year 1985), when the GWL increased to a level of 34 cm underground. The lowest annual average value of the GWL is determined for 2020 (in the case of the 2010 time horizon, it was

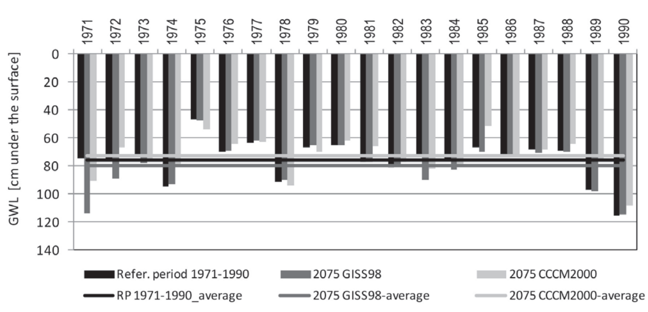

Fig. 8 *Course of the annual average groundwater level (GWL) in the Zelienka wetland calculated with the HYDRUS ET model for the 1971-1990 reference period and the GISS98 and CCCM2000 climate change scenarios for the time horizon 2075.*

2012/1 PAGES 29 — 34

the year 1990), when the GWL was 99 cm underground, and for the year 2040 (in the case of the 2030 time horizon, it was the year 1990), the water level will be 109 cm underground.

4. CONCLUSION

Wetlands are one of the most valuable ecosystems that provide social, economic and also significant ecological benefits. Ongoing climate change may cause indirect changes in the hydrology of an ecosystem, which could endanger rare wetland flora and fauna.

Therefore, we decided through this paper to analyze the impact of climate change on the course of the groundwater level. For this purpose, the HYDRUS-ET mathematical model was used, which is an appropriate tool to simulate the course of GWL. Its suitability for the Zelienka wetland was verified by comparing the simulated and measured data of GWL from the years 2001 and 2002. For this case the monthly and annual average values for the different climate scenarios GISS98, CCCM2000 and time horizons 2010, 2030 and 2075 as well as the reference period 1971-1990 were calculated.

A comparison of the reference period 1971-1990 with the CCCM2000 scenario for the time horizons 2010, 2030 and 2075 shows that there is an increase in the groundwater level in all the time horizons. A comparison of the reference period 1971-1990 with the GISS98 scenario for the time horizons 2010, 2030 and 2075 indicates that there is a slight decrease in the groundwater level in all the time horizons. It can be seen from these outputs that the course of the groundwater level according to the CCCM2000 scenario has an increasing trend compared with the GISS98 scenario.

In conclusion, the results of this analysis show that the climate change in the case of the Zelienka wetland in Záhorie should not negatively influence the level regime of the wetland and endanger the existence of the wetland.

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2012/1 PAGES 29 – 34

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