Modeling of stream-aquifer interactions for the Przemkowsko-Przeclawskie wetlands restoration planning

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Summary

The aim of this research was to study the possibilities of successfully rewetting an area of the Przekowsko-Przeclawskie Wetlands, situated in South-west Poland. Modeling of groundwater level dynamics, using the groundwater model Modflow, proved that the inundation of the investigated area was possible in spring and in summer of a wet and an average year through raising water levels in the existing channels. In a dry year the inundation was not possible even though the water levels in channels were raised to the maximum level and the groundwater levels desired for wet meadows were not reached.

Key index words: wetlands restoration, modeling, groundwater

Introduction

Przemkowsko- Przeclawskie Wetland is an example of a river-fed marsh area where the natural environment was significantly altered due to the construction of a land reclamation system which was in operation for several years. The agricultural use was subsequently abandoned and followed by decades of no proper water management. The comparative analysis of archive and actual cartographic materials covering the area of Przemkowsko-Przeclawskie Wetlands provided an insight to the primary type of the wetland system and the original undisturbed shape of the river network. From this material we can assume that the original extent of wetlands was about 4000 ha (Brandyk *et al.,* 2005). It was also found that in its natural state, Przemkowsko- Przeclawskie wetlands were inundated by surface waters from the meandering Szprotawa River and its tributaries. Land reclamation works, carried out to canalize all the streams within the boundaries of the investigated area, drained the site and it was no longer inundated. the present day restoration of Przemkowsko-Przeclawskie Wetlands requires the reconstruction of the primary course of the Szprotawa River and its tributaries. According to the current investigations these actions are not possible on account of the present social and economical issues. Hence, a possible solution is to raise the water levels in the existing network of channels in order to increase the groundwater levels and allow for repeated area inundation. The desired increase of groundwater levels is strongly dependent on the rate of stream-aquifer flows that result from the existing magnitude of hydraulic contacts between the streams and the aquifer. The levels are also conditioned by water levels in streams. Studies focused on using the recharge to groundwaters from the existing streams for the purpose of partial restoration of wetlands, have been carried out for many areas. Those studies revealed that the range and duration of inundation obtained by groundwater table mounding was usually much smaller than that originating from peak surface water flows (Bosewell *et. al.*, 2007; Stewart *et al.*, 1998; Thompson *et. al.*, 2004; Tiemeyer *et al.*, 2006). It was also found that in spring and early summer maintaining high water levels in channels, usually combined with periods of high precipitation, enhanced inundation. However, in mid and late summer and in autumn it wasn't possible, mostly due to high evapotranspiration rates (Tiemeyer *et al.*, 2006).

In our study we have focused on identification of the maximum wetland area, which can be restored using the groundwater resources. This measure is proposed by local authorities and the aim of the research is to assess its viability. The second aim is to restore wet meadows, which have a significant biodiversity value with respect to bird species and plant communities, but do not require such frequent inundation.

Materials and methods

In order to outline the best approach for restoration of Przemkowsko–Przeclawskie Wetlands making use of stream-aquifer flows, the existing data were collected to generate a groundwater flow model.

The data included hydrogeological maps and cross-sections as well as available borehole data. A monitoring network of groundwater observation wells was set up on the area of the wetlands along with water gauges on the main watercourses (Fig. 1). Samples from the uppermost soil layers were taken for laboratory analysis of saturated, vertical and horizontal hydraulic conductivities. Conductivities of deeper layers were known from previous hydro-geological expertise and pumping tests. The interaction flows between streams and aquifers were assessed by the field measurements of the vertical hydraulic conductivity of the streambed sediments. Meteorological data from nearby stations was gathered in order to estimate the precipitation rates and to calculate the potential evapotranspiration rates with the use of Penman method (www.fao.org).

The groundwater flow model Modflow (Bruen *et al.,* 2002) was used to perform the necessary simulations, since the modeled stream-aquifer interactions concerned the cases of fully saturated flow and this model is suited to handle such cases. It applies a mass conservation law to account for the balance of groundwater flows. In this model the hydrogeological system is represented by a number of layers containing computational cells assigned to main hydrostratigraphic units. The groundwater system within the area of the wetlands was schematized in two model layers according to the existing recognition of hydro-geological conditions. The first layer was assigned to a shallow groundwater level present in sands and loamy sands covered by peat. The second model layer represented the main sandy aquifer which was separated from the first layer by several metres of low permeability loams. The main aquifer was underlain by impermeable clay layers.

After setting the model, calibration processes took place. This was carried out by a trial and error procedure for steady-state conditions during April, May and June of 2005 and 2006. The fluxes resulting from the disproportion between the rainfall and evapotranspiration values were subject to calibration as they were constrained by the field measurement errors of meteorological parameters and were allowed to vary spatially according to the extents of recognized vegetation types. The validation of the model was performed by transient simulations with a daily time step for the period beginning on 15th June 2005 and finishing on 15th March 2006, and again for the period between 20th May 2006 and 15th March 2007. Following from this, the analyses of precipitation and potential evapotranspiration distributions for a period 1964-1984 were carried out, determining years with wet, average and dry hydro-meteorological conditions basing on statistical calculations (Cressie, 1991). As a result of this analysis, the following years have been chosen for simulations of groundwater flow: 1973 (dry year), 1975 (average year) and 1981 (wet year). The resulting groundwater levels were analyzed in terms of causing an inundation or meeting the set criteria, under different water levels in channels. The criteria outlined in Table 1 were used.

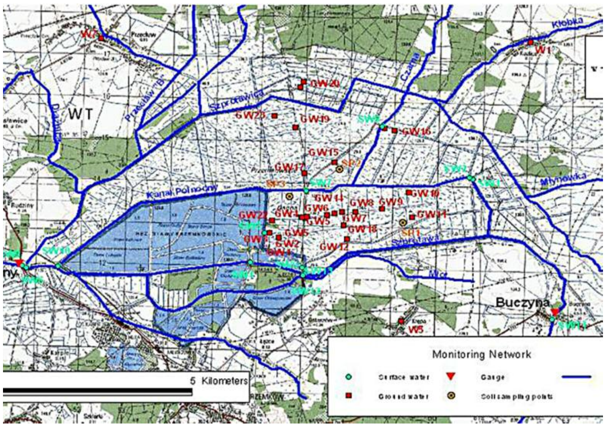

Figure 1. The monitoring network of Przekowsko-Przeclawskie Wetlands

The criteria set for restored habitat types were adapted from the studies on the Biebrza River in Poland (Mioduszewski *et. al.*, 1996; Oswit, 1991; Okruszko, 2005). Simulations were performed for 3 years, with two analysed periods for each year: April to June (steady state spring conditions), July to September (steady state summer conditions) and for each period the simulations included both existing water levels in streams and levels in streams risen to maximum by blocking the outflow from the investigated area (Table 2).

Table 1. Criteria used to determine habitats for restoration

Habitat type	Depth to ground water table –h [cm]	
	spring	summer
Wetland areas	≥0	<-30 ; 0>
Wet meadows	>-20	<-30 ; -60>
Degraded meadows	<-20	<-60

Table 2. Analysed simulation variants

Variant	Average ground water levels in spring [cm]	Average ground water levels in summer [cm]	Year
Existing situation	-45	-60	1973-dry
	-20	-40	1975-average
	+10	-20	1981-wet
Blocked outflow	-40	-43	1973-dry
	0	-35	1975-average
	+30	-10	1981-wet

Results

Calibration and verification

The outputs of the model were, first of all, the flow of groundwater levels for the periods 15th June 2005-15th March 2006 and from 20th May 2006-to 15th March 2007 which enabled us to estimate the quality of the model performance. A close match of simulated and observed groundwater levels for these periods proved a satisfactory result for the model calibration. Mean absolute observed error was equal to 0.07m while maximum absolute error ranged 0.21m for the first period . During the second period these errors were appropriately equal to 0.21m.which were the values acceptable also in other studies (Thompson *et. al.*, 2004; Tiemeyer *et al.*, 2006)

Simulation

The results obtained from modeling included average groundwater table position and areas covered by certain habitat types obtained by comparing the average groundwater table with the assumed criteria. These results are presented in Tables 2 and 3.

Conclusions

The restoration of wetland conditions with the use of groundwater resources is difficult and it is possible only on part of the investigated area. The inundated areas covered only a small percent in comparison to the primary inundation extent and they occurred during a wet year 1981 (15.5% of the area) and in the average year 1975 (about 10%).

Table 3. Areas covered by certain habitat type

Variant	Area of wetlands [ha]	Area of wet meadows [ha]	Area of degraded meadows [ha]	year
Existing situation	0	0	4000	1973-dry
	400	1500	2100	1975-average
	570	2000	1430	1981-wet
Blocked outflow	0	0	4000	1973-dry
	470	1800	1730	1975-average
	620	2100	1280	1981-wet

The criteria for wet meadows were satisfied in all periods except for the dry year. Blocking the outflow didn't significantly alter the extent of the area covered by the wetlands or wet meadows and it had little effect on the groundwater table depth in all analyzed years. Only in the average year (1975) did blocking of the outflow result in an increase of wet meadow area by 20%.

Maintenance of inundation in summer (especially in July and August) for the area of Przemkowsko– Przeclawskie Wetlands was found to be possible as in other case studies (Bradley *et al*., 2005), confirming the results found in other works on wetland restoration. The groundwater levels desired for wet meadows are achieved in drier periods, which is also typical for many managed wetlands.

The measure to restore the wetland area by using groundwater resources, planned by local authorities, will have a limited effect as illustrated by the studies presented here. The hydrological situation of the restored wetland is in fact improved but this improvement is on such a small scale that it still excludes the prospects of restoration of the complete studied area.

The change of the hydrological alimentation type from river-fed to groundwater-fed for Przemkowsko-Przeclawskie Wetlands is related to significant loss of the wetland area because of the limited water resources

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