Water resources management – a possibility for drought mitigation in wetlands?

O. Dietrich[1], H. Koch[2] & S. Schweigert[1]
[1]*Leibniz-Centre for Agricultural Landscape Research (ZALF) eV, Institute of Landscape Hydrology, Germany*
[2]*Brandenburg University of Technology Cottbus, Hydrology and Water Resources Management, Germany*

Abstract

The water balance of many wetlands in the North-East German Lowland is dominated by water resources management systems with drainage and sub-irrigation. These systems are integrated in the water resources management system of their whole river basin. Scenario investigations show the possibilities and constraints of different water resources management options within the wetland and in the basin. For the Spreewald wetland strategies for the mitigation of negative impacts of climate change are presented as an example.
Keywords: wetlands, water resources management, drainage, sub-irrigation, water balance model, climate change.

1 Introduction

Most of the wetlands in the North-East German Lowland are fens. After the last ice age they developed in spite of the climatic conditions with a mean annual precipitation of approximately 500 mm per year, because they got sufficient recharge from their basin and the discharge was blocked by natural barriers. In the last two centuries most of the fens were drained for agricultural land use. However, because of the low precipitation, the drainage systems were completed with a number of weirs as a prerequisite for intensive agricultural production in the 1970s and 1980s. Therefore, these regions have complex water resources management systems today, which are often integrated in the water resources management system of the whole river basin.

WIT Transactions on Ecology and the Environment, Vol 103,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WRM070061

The last decade, with dry summers and hot temperatures, shows that there is an increasing risk of droughts in these wetlands. Climate models forecast an additional threat, with increasing temperatures and decreasing precipitation in the summer months for the next few decades in north-east Germany. On the other hand, there are a lot of ways of enabling these areas to be used once more with groundwater levels more typical for wetlands. To do so, it is necessary to develop new water management strategies taking changing climatic conditions into account. This process can be successfully planned with the help of numerical models. The model systems WBalMo Spreewald (Dietrich *et al* [1]) for the Spreewald wetland and WBalMo Spree/Schwarze Elster (Kaltofen *et al* [2], Koch *et al* [3]) for the Spree River basin are suitable tools for such a task. They were developed, tested and used for scenario investigations in the context of global change within the research project GLOWA-Elbe (www.glowa-elbe.de). In this paper some scenario results will be presented and discussed.

2 Study region

The Spreewald wetland is situated about 70 km south-east of Berlin, located within the Spree River basin (Fig. 1). It is one of the most significant wetlands in Germany. The lowland region has an area of 320 km². It is characterized by a low mean annual precipitation of about 530 mm for the period 1961-1990 (HAD [4]) and rather high potential evapotranspiration (FAO grass reference evapotranspiration) of about 610 mm for the same period.

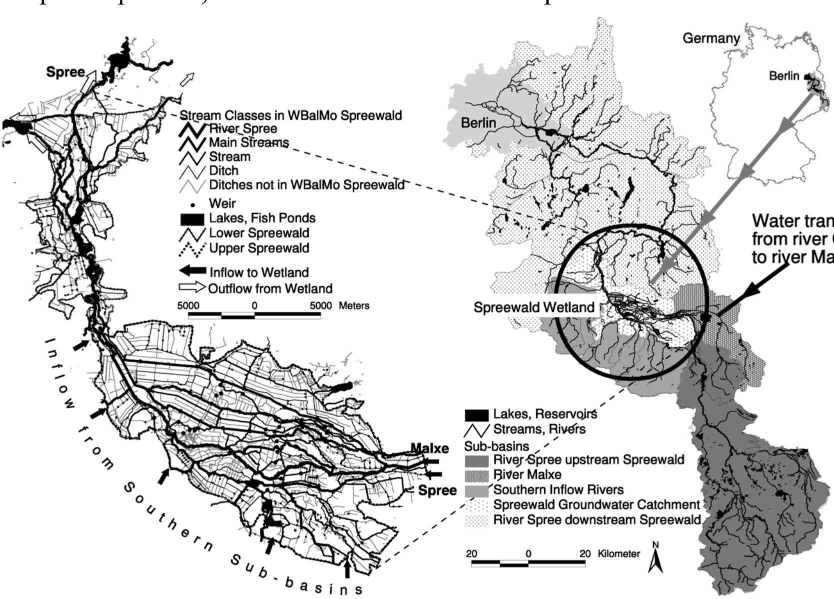

Figure 1: Running water system (classified for the water balance model WBalMo Spreewald) with weirs, main inflow and outflow of the Spreewald (left) and location of the Spreewald wetland south-east of Berlin in the Spree River basin (right).

The wetland soils are dominated by groundwater-influenced sands (49%), fens (33%) and loamy soils (18%). The land use of the wetland area is characterized by extensive grassland (44%), fields (23%) and forests (20%).

The wetland has a very dense stream and ditch system of about 1,600 km in length with more than 600 weirs to regulate ditch water and groundwater levels (Fig. 1, left). Therefore, the water balance of the Spreewald region is strongly influenced by the water management system within the wetland.

The Spreewald wetland is supplied with water from the Spree River (2,535 km²), the Malxe River (345 km²) and the southern sub-basins (1,160 km²) (Fig. 1, right). The water balance in these basins has been influenced by a number of opencast mines for more than 100 years. In the 1980s the pumping rates of mine discharges increased up to 30 m³/s (Grünewald [5]). The extensive groundwater drawdown in the mining region led to a large groundwater deficit in the basin. Today most of the opencast mines are closed. So the amount of mine discharges in the Spree River decreased to about 10 m³/s and will be reduced to 0 m³/s by 2040. Additionally, the residual mining pits have to be refilled with water and the man-made drawdown is being reverted. As a consequence of the current high water demand of the basin, water deficiency situations for the wetlands occur increasingly during the vegetation periods.

3 Method

The models used, WBalMo Spreewald and WBalMo Spree/Schwarze Elster, consider aspects of the water resources management in the wetland and in the basin. WBalMo Spreewald is a combination of a water management model (WBalMo®, WASY [6]) and a water budget model for wetlands with drainage / sub-irrigation systems (WABI, Dietrich *et al* [7]). This combination is a solution to fulfil the complex requirements of the wetland region. WBalMo Spree/Schwarze Elster is a complex water balance model with a great number of different water users in the basin.

The model system WBalMo represents the hydrological processes and the water management in a river basin. River basins are represented by simulation sub-basins, running waters, balance profiles, water users and reservoirs. The input values are stochastically generated time series. The water utilization processes are reproduced deterministically. The time step is one month.

WABI is a simple water balance model for groundwater-influenced areas with drainage and sub-irrigation systems. The study site is divided in sub-areas, the smallest area in which the groundwater level can be regulated separately. One important assumption is a horizontal groundwater level in each sub-area. The time step is also one month. The model requires target water levels and inflows for each sub-area. WABI is directly coupled to WBalMo. Each WABI sub-area is one water user in WBalMo. The sub-model WABI requires information about the elevation distribution connected with land use and soil types of each sub-area as well as storage for each sub-area.

In the model WBalMo Spreewald the wetland's complex system of streams and ditches was simplified. Only watercourses which are important for drainage and water surplus for the wetland sub-areas are considered. For 86 bifurcations of watercourses special rules were developed on the basis of expert knowledge, the current water management practice or depending on the water demand of water users downstream from the bifurcation. Changing distribution rules is one way of simulating different water management strategies with the model. The wetland area was divided into 197 sub-areas. Every sub-area is represented by one water user in the model. The calibration and validation of the model WBalMo Spreewald is described in detail in [1].

WBalMo Spreewald requires input data for precipitation, potential evapotranspiration and the inflow from the sub-basins into the wetland and the sub-areas at the boundary of the wetland. The climatic input data were prepared by project partners using the climate model STAR (Werner and Gerstengarbe [8]). The inflow from the sub-basins was calculated using the water management model of the Spree River basin WBalMo Spree/Schwarze Elster [2] based on the same STAR model climate data. Input series were made available for each month from 2003 to 2052 with 100 realizations of every year (Monte Carlo Simulation). The modelled time range of 50 years was divided in ten 5-year periods. Within each 5-year period the management options, climate trends, water demands of water users, etc. are unchanged.

4 Scenarios

The WBalMo models were used to determine the impacts of different water management options on the water balance of the Spreewald wetland under changing global conditions. Scenarios were defined as combinations of boundary conditions and water resources management options in the wetland. In this paper the boundary conditions for the wetland water balance are climate change (Wechsung *et al* [9]) and two water resources management options in the Spree River basin. The first option represents the current management practice and the second a water transfer of at most 2 m^3/s from the Odra River to the Malxe River (Koch *et al* [10]) (Fig. 1, right). The two water resources management options of the basin were combined with options in the wetland: (1) the current management practice and (2) another distribution of the inflow water within the wetland (Dietrich *et al* [11]).

Table 1: Definition of scenarios by combination of different water resources management options in the basin and in the wetland.

Scenario name		Water resources management in basin	Water resources management in wetland
1	Basis	Current practice	Current practice
2	Redistribution	Current practice	Redistribution of basin surplus within wetland
3	Transfer	Water transfer from Odra River	Current practice
4	Transfer with redistribution	Water transfer from Odra River	Redistribution of basin surplus within wetland

5 Results and discussion

The statistical evaluation of the model results was made for each 5-year period. In the following we compare and discuss the results of the period 2003-2007 (P1) with the last period 2048-2052 (P10). In the figures the first period of the basis scenario is also the reference status for the other scenarios. The bars in the figures represent the 50th percentile of 500 values per month. The caps show the range between the 20th and 80th percentiles.

5.1 Boundary condition – climate change

The climatic boundary conditions are the same in all scenarios. For a better interpretation of the model results the impact of climate change is represented by the climatic water balance (Fig. 2). Already, the balance of P1 shows a deficit for the months from April to September. But from June to August, especially, the deficit will clearly increase up to the last period (P10). This increasing deficit influences the water demand in the wetland, but also the inflow from the basin.

Because the period from April to September is most interesting for water scarcity situations in the wetland, the following figures will only show percentiles of this part of the year.

5.2 Recharge from basin into the wetland

The inflow from the basin will decrease in the summer months up to 2050 (Fig. 3). The reasons are the changed climatic conditions as well as the planned development of the mining activities in the basin. The inflow from the Malxe River, especially, will decrease in the future, because today there are two large opencast mines in this sub-basin, which are going to close by 2030. Then the pumping of mine water will stop and additional water is needed to refill the residual mining pits.

The water resources management option "water transfer from the Odra River into the Malxe River" could improve the water supply situation (Fig. 3). However, the volume assumed in the scenario is not sufficient to compensate for the decrease in the water inflow of the whole Spree River basin upstream of the Spreewald wetland due to climatic changes and a lack of mine discharges.

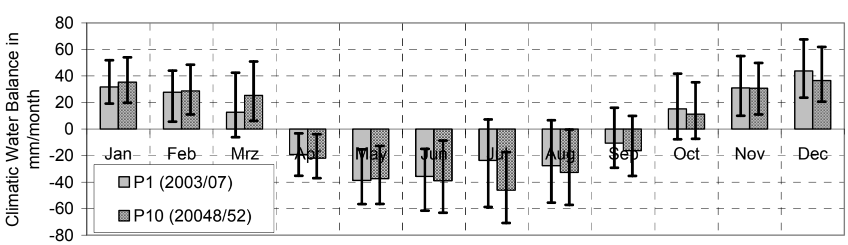

Figure 2: Comparison of the climatic water balance in the periods 2003-2007 (P1) and 2048-2052 (P10).

www.witpress.com, ISSN 1743-3541 (on-line)

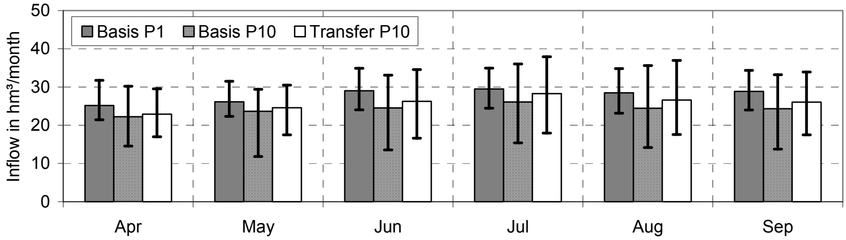

Figure 3: Change of inflow into the wetland in the periods 2003-2007 (P1) and 2048-2052 (P10) depending on different water management measures in the basin (basis, water transfer from Odra River).

5.3 Water demand of the wetland

The development of the wetland water demand is shown using the example of July for all ten 5-year periods. The values are influenced by the water balance parameters of precipitation, actual evapotranspiration and the water storage deficits of the previous month. The results in Fig. 4 show an increasing water demand of 35 mm between the median of the first and last 5-year period. The reasons for this are the changed climatic conditions with lower summer precipitation and higher potential evapotranspiration. This will also lead to higher actual evapotranspiration because of the near-surface groundwater levels. The consequence is that the wetland depends more on the basin inflow.

5.4 Water withdrawal of the wetland

Figure 5 shows the water withdrawal for all scenarios in P10 in comparison to P1 of the basis scenario. In all scenarios there is an increase in the water withdrawal from July to September because of the higher water demand. But the limited water yield from the sub-basins limits the withdrawal. Different water resources management options improve the utilisation of the existing water yield, but the increase in available water can not compensate for the overall increase in water demand (10 mm versus 35 mm in July). The consequences are decreasing groundwater levels in the wetland and decreasing outflow from the wetland.

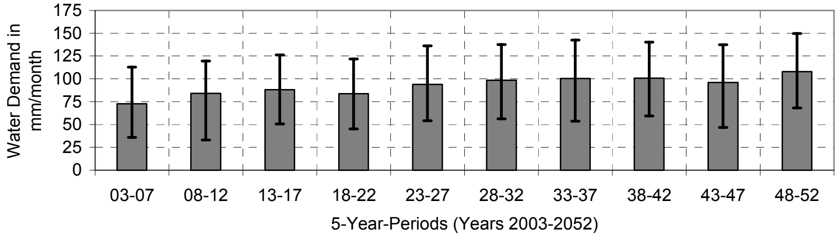

Figure 4: Water demand of the whole wetland area (basis scenario, July).

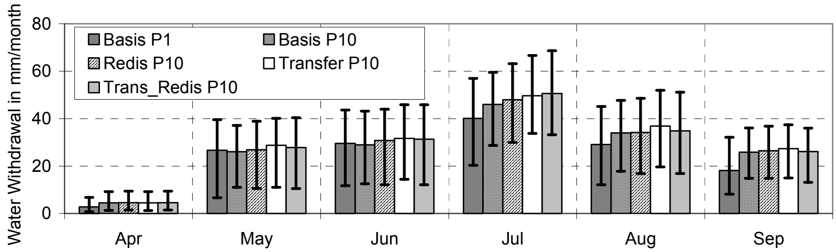

Figure 5: Water withdrawal of the whole wetland area from basin inflows in the periods 2003-2007 (P1) and 2048-2052 (P10) depending on different water management measures.

5.5 Groundwater levels in the wetland

The maps in Fig. 6 illustrate of the change of groundwater levels in July of P1 and P10 in the different scenarios. Figure 6A shows few differences in the central parts of the Upper and Lower Spreewald wetland. These parts are predominantly supplied with water from the main inflow of the Spree River. Only the sub-areas in the Upper Spreewald wetland, predominantly supplied with water from the Malxe River, have decreasing groundwater levels. The reasons are explained in chapter 5.2. The largest problems will arise in the border parts of the wetland because these sub-areas can only receive water supply from relative small sub-basins. It is difficult or even impossible to transfer water from the main inflow of the Spree River to all of these parts.

The different water resources management options (Fig. 6B-D) improve the situation in some parts of the Spreewald wetland. The redistribution of water from the Spree River inflow in the northern part of the central Upper Spreewald (in the basis scenario supplied by the Malxe inflow only) and the concentration on the central parts of the wetland, which are the most important parts for nature protection, lowers the threat of water scarcity in these parts. But it also leads to drier situations in other parts of the wetland.

Transferring water from the Odra River to the Malxe River improves the groundwater levels in the wetland parts predominantly supplied with Malxe water without a negative impact on other parts (Fig. 6C). The fourth scenario shows the largest increase in the groundwater levels (Fig. 6D). However, no management scenario leads to an improvement in the most-threatened border parts compared to the basis scenario in P10.

5.6 Discharge below the wetland

The discharge below the wetland is important for the Spree River and water users along the river downstream of the Spreewald wetland. Because of the water demand of these water users, there should be an outflow of the Spreewald wetland into the Spree River of approximately 12 hm³ per month. Already in

July of P1 of the basis scenario this value is reached in 50% of the years only (Fig. 7). No management scenario improves this situation distinctly. The reason is the large water demand of the wetland.

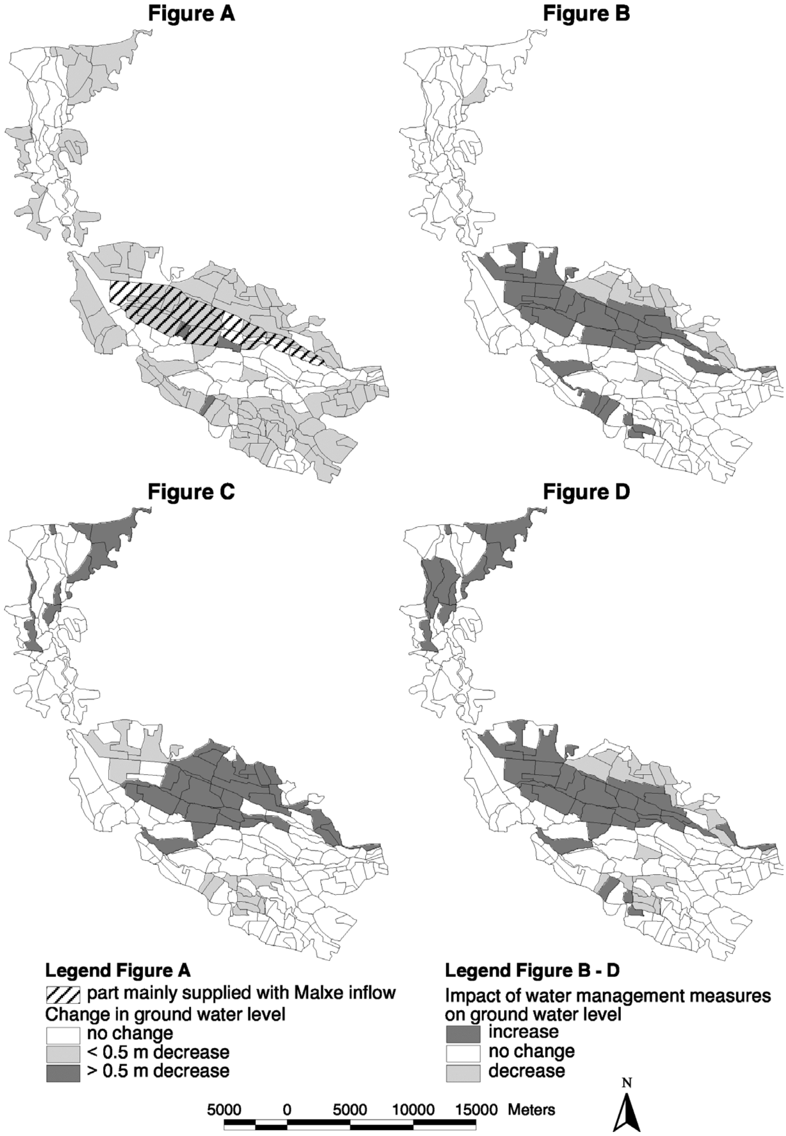

Figure 6: Difference between the July groundwater levels of the basis scenario for the periods 2003-2007 and 2048-2052 (A) as well as the difference between the basis scenario of the period 2048-2052 and the redistribution scenario (B), the transfer scenario (C) and the transfer with redistribution scenario (D) for 2048-2052.

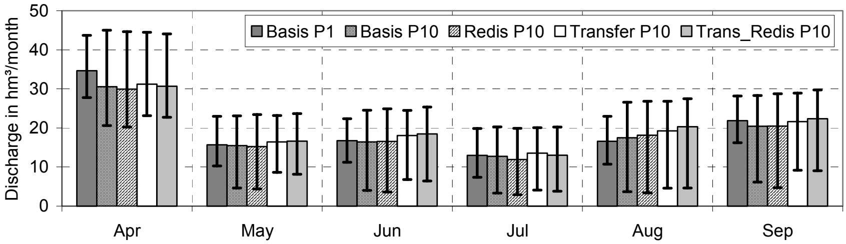

Figure 7: Discharge below the wetland in the periods 2003-7 (P1) and 2048-2052 (P10) depending on water management options.

The results show also increasing problems in the drier years. The 20th percentile values undershoot the 12 hm³ per month in P1 in the basis scenario only in July. In P10 this value will be undershot more distinctly from May to September. This could be a large problem in the Spree River basin in the future.

6 Conclusions

In connection with the WBalMo Spree/Schwarze Elster for the Spree River basin, the WBalMo Spreewald model offers a way to integrate water budget modelling in wetland areas and the water resources management of the whole basin in one model. It can be used to analyse the impacts of changing boundary conditions (meteorological, hydrological, economic conditions) as well as management options and to develop strategies to reduce unwanted impacts of global change.

The results show that climate change may produce large problems for wetlands in humid climatic zones in the future, especially if there are already water deficits under the present conditions. In the Spreewald wetland the water demand of the wetland area will increase in the future. The inflow from the basin will be insufficient to compensate for this increase in the whole region. Therefore, water deficit periods will occur more frequently. The consequences of frequent water deficits are deeper groundwater levels in summer, which differ depending on the inflow conditions and water distribution within the wetland.

The results of the scenarios are only a few examples of how water resources management strategies can help to reduce unwanted impacts and to mitigate droughts in wetlands in the future. The investigation of further strategies is necessary to find the best solution for all water users in the wetland and downstream. A socio-economic evaluation of the scenarios is also needed. The task is to find strategies which are seen by all water users as a good compromise.

Acknowledgements

We would like to thank the Federal Ministry of Education and Science for sponsoring the research project GLOWA-Elbe (FK: 07 GWK 03) and the authorities of Brandenburg for supplying the data basis for the study region. We would especially like to thank our colleagues from the Potsdam Institute for Climate Impact Research for supplying the time series of climate data as well as for their good cooperation on the project.

References

[1] Dietrich, O., Redetzky, M. & Schwärzel K., Wetlands with controlled drainage and sub-irrigation systems-modelling of the water balance. *Hydrological Processes*, DOI: 10.1002/hyp.6317, 2007.

[2] Kaltofen, M., Koch, H., Schramm, M., Grünewald, U. & Kaden, S., Application of a long-term water management model for multi-criteria assessment procedures – Scenarios of global change in the Spree catchment influenced by lignite mining. *Hydrology and Water Resources Management*, **48(2)**, pp. 60-70, 2004.

[3] Koch, H., Kaltofen, M., Grünewald, U., Messner, F., Karkuschke, M. Zwirner, O. & Schramm, M., Scenarios of water resources management in the Lower Lusatian mining district, Germany, *Ecological Engineering*, **24(1-2)**, pp. 49-57, 2005.

[4] HAD, Hydrologischer Atlas von Deutschland. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Hrg.), 1998.

[5] Grünewald, U., Water resources management in river catchments influenced by lignite mining. *Ecological Engineering*, **17(2-3)**, pp. 143-152, 2001.

[6] WASY, WBalMo 3.0 – Interactive Simulation system for planning and management in river basins. User's Manual, WASY Gesellschaft für wasserwirtschaftliche Planung und Systemforschung mbH, Berlin, 157 p., 2006.

[7] Dietrich, O., Dannowski, R. & Quast, J., GIS-based water balance analyses for fen wetlands. In Holzmann H. & Nachtnebel, H.P. (eds.), Application of Geographic Information Systems in Hydrology and Water Resources Management. Vol. of Poster Papers, Vienna, pp. 83-90, 1996.

[8] Werner, P.C. & Gerstengarbe F.-W., Proposal for the development of climate scenarios. *Climate Research* **3**, pp. 171-182,. 1997.

[9] Wechsung, F., Becker, A. & Gräfe, P. (eds.), Integrierte Analyse der Auswirkungen des Globalen Wandels auf Wasser, Umwelt und Gesellschaft im Elbegebiet. Weissensee-Verlag, Berlin, 405 pp., 2005.

[10] Koch, H., Kaltofen, M., Schramm, M., Grünewald, U., Adaptation strategies to global change for water resources management in the Spree river Catchment, Germany. *International Journal of River Basin Management*, 4(4), 2006.

[11] Dietrich, O., Redetzky, M. & Schwärzel K., Modeling Water Balances of Wetlands with controlled Drainage and Sub-irrigation Systems. In: Kotowski, W., Maltby, E., Miroslaw-Swiatek, D., Okruszko, T. & Szatylowicz, J. (eds.), Wetlands: modelling, monitoring, management. Taylor & Francis, The Netherlands. A.A. Balkema Publisher (in press), 2007.