

Water Management and Retention Opportunities Along the Hungarian Section of the Drava River



Ali Salem, József Dezső, Mustafa El-Rawy, and Dénes Lóczy

Abstract The water budget of wetland areas and floodplains has been altered due to human intervention and water regulation works. To protect agricultural productivity, ecosystem services, and wetland habitats on the Hungarian side of the Drava River floodplain, this research developed a unified management approach for floodplain rehabilitation through natural water retention. The interaction of a natural water reservoir with the groundwater system was assessed numerically using MODFLOW-NWT. The model was calibrated (correlation coefficient 0.93) with a mean error of 0.04 m and a mean absolute error of 0.05 m. The natural water reservoir for the Korcsina subarea was simulated for +2 m surplus water level and $2 \text{ m}^3 \text{ s}^{-1}$ filling rate ($172,800 \text{ m}^3 \text{ days}^{-1}$). The first 1-m water level rise increases the saturation of soil pores, while the second meter works as open excess water, surface water body (intermittent lake). The total upfilling (+2 m relative water level) at the Korcsina subarea requires 33 days and $6,625,675 \text{ m}^3$ of water. The discharge (seepage) period lasted 14 days.

Keywords Water budget · Floodplain rehabilitation · Natural water reservoir · MODFLOW-NWT

A. Salem (✉)

Doctoral School of Earth Sciences, University of Pécs, Ifjúság útja 6, H-7624 Pécs, Hungary
e-mail: eng_ali_alem2010@mu.edu.eg

A. Salem · M. El-Rawy

Civil Engineering Department, Faculty of Engineering, Minia University, Minia 61111, Egypt

J. Dezső · D. Lóczy

Institute of Geography and Earth Sciences, Faculty of Sciences, University of Pécs, Ifjúság útja 6, H-7624 Pécs, Hungary

M. El-Rawy

Civil Engineering Department, College of Engineering, Shaqra University, Dawadmi, Ar Riyadh 11911, Saudi Arabia

1 Introduction

More than 95% of floodplains and half of the wetlands have been converted to urban and agricultural land [1]. Consequently, the availability of water in floodplain has been changed. The incision of the Drava River leads to groundwater levels 1.5 to 2.5 m lower and deteriorated the water budget of the floodplain [2, 3]. Moreover, human interventions (river regulation, hydroelectric plants, etc.) generated drought hazard and water shortage in the floodplains of Hungary [3], jeopardizing agricultural production and ecosystem services [4]. Floodplain rehabilitation requires that groundwater should be raised to levels comparable to those before regulations.

Former oxbows, paleo-meanders, and back swamps can function as natural water reservoirs, suitable for the storage of surplus water provided from adjacent streams [5]. The main objective of this research was to develop a unified management approach for water retention along the Hungarian Drava section through the implementation of a natural reservoir.

2 Study Area

The study area is located along the Lower Drava River, SW-Hungary. The floodplain of silty-sandy alluvium and fluvisols lies at 97–107 m elevation, crossed by 13 tributary streams, with 20 side channels, and 18 oxbow lakes [2]. The physical properties of soils are controlled by subdued ridge-and-swale topography [6]. The Korcsina subarea is a paleo-channel system of potential water reservoir (Fig. 1).

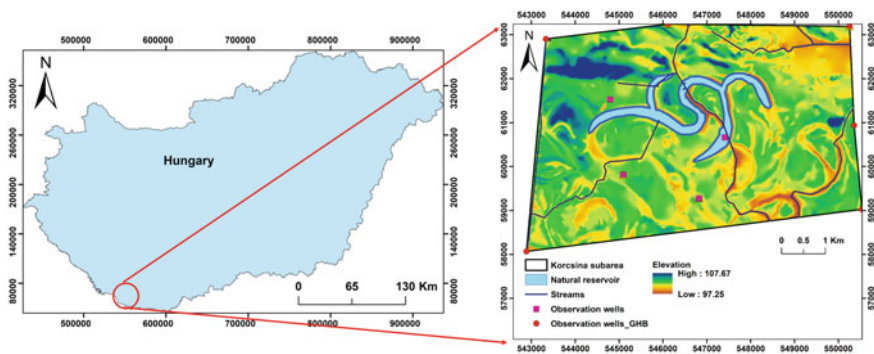


Fig. 1 Location of study area and elevation map

3 Groundwater Flow Model Setup

The MODFLOW-NWT model [7] with ModelMuse [8], which is a graphical user interface, was used to simulate 3D groundwater flows in quadratic 30×30 m cells. Ground penetration radar records and auger holes show high heterogeneity in the hydraulic properties of sediment at 0–10 m [9]. Long-term average annual precipitation and temperature are 700 mm/year and 10.5 °C, respectively. Hydraulic conductivity was measured using the fall head method. The N, S, and E boundaries were represented by general head boundary (GHB) based on the records from four observation wells. The conductance of GHB was initially set to $5 \text{ m}^2 \text{ days}^{-1}$. The Sió-pusztai and Korcsina streams were assigned by a river package. Groundwater recharge and evapotranspiration were calculated using WetSpass-M, a spatially distributed water balance model [10].

A steady-state model was developed to calibrate the original model using groundwater levels for one auger hole and three observation wells. The calibrated values of hydraulic conductivity resulted in five zones: 300, 150, 60, 17, and 0.03 m days^{-1} . The conductance of stream beds was $30 \text{ m}^2 \text{ days}^{-1}$, while the conductance of the GHB boundary changed to $15 \text{ m}^2 \text{ days}^{-1}$. The calibrated results showed good agreement (correlation coefficient: 0.93, mean error: 0.04 m, and mean absolute error: 0.05 m).

3.1 Water Balance

In the water balance of the calibrated model (Table 1), total groundwater recharge was $29,765,891 \text{ m}^3 \text{ days}^{-1}$, i.e., 70% of the total inflow to the aquifer, while most of the aquifer outflow was directed to the river and comprised by evapotranspiration, $25,971 \text{ m}^3 \text{ days}^{-1}$ and $2,703 \text{ m}^3 \text{ days}^{-1}$, respectively.

Table 1 Water balance for the simulated steady-state model

	In		Out		In–Out ($\text{m}^3 \text{ days}^{-1}$)
	($\text{m}^3 \text{ days}^{-1}$)	%	($\text{m}^3 \text{ days}^{-1}$)	%	
Northern boundary	7162	16.99	1532.70	3.64	5,629.30
Eastern boundary	0.00	0.00	698.68	1.66	–698.68
Southern boundary	1,498.40	3.55	11,254.00	26.69	–9755.60
River	3,736.83	8.86	25,971.71	61.60	–22,234.88
Recharge	29,765.01	70.60	0.00	0.00	29,765.01
Evapotranspiration	0.00	0.00	2,703.46	6.41	–2,703.46
Total	42,162.24	100.00	42,160.55	100.00	1.69

3.2 Scenarios of Water Retention Simulation for Potential Water Reservoirs

The planned reservoir (Fig. 1) was simulated by the reservoir package. Re- and discharge conditions were based on +2 m vertical water level increase. Feeding was from Korcsina channel at $2 \text{ m}^3 \text{ s}^{-1}$ ($172,800 \text{ m}^3 \text{ days}^{-1}$) discharge to reach +2.0 m elevation in 33 days with $6,625,675 \text{ m}^3$ water. During the recharge period, subsurface seepage tended to increase (Fig. 2a). The difference between the amount of filling and seepage gave the storage volume at the natural reservoir site (a paleo-channel). The discharge caused by subsurface seepage and less evapotranspiration showed that this reservoir system lost the stored water within 2 weeks (Fig. 2b).

The first 1-m increase causes soil saturation, while further filling creates a surface water body (intermittent lake). The simulated groundwater head at the end of recharge and discharge periods is shown in Fig. 3a,b. The subsurface inflow flows through the

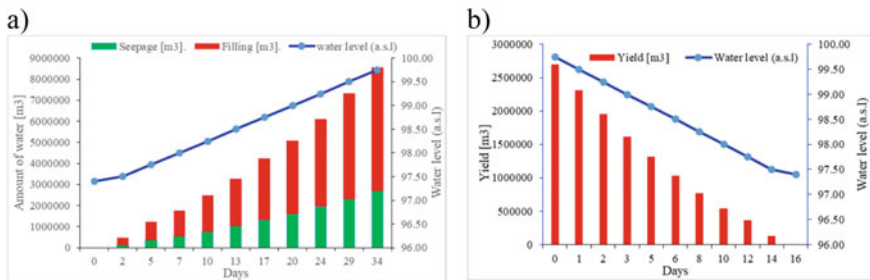


Fig. 2 Filling volume, seepage [m³], and water level of the reservoir for the recharge period (a) and water loss from the reservoir related to water level (b)

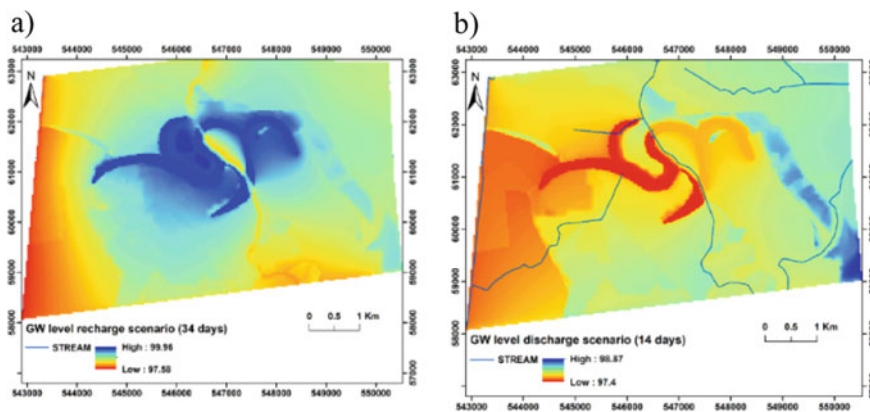


Fig. 3 Simulated groundwater head at the end of recharge period on the 34th day (a) and for the discharge scenario on the 14th day (b)

NE boundary while the groundwater levels decreased in the western part. Seepage creates a subsurface water surplus in the root zones of the surrounding area.

4 Conclusion

In past centuries, human activities and Drava River incision increased the drought hazard in the Drava floodplain through lowering the groundwater table. Consequently, agricultural production and wetland habitats reached a serious situation. The study investigated water retention opportunities in the desiccating lower Drava floodplain through the implementation of natural reservoirs. The Korcsina subarea was simulated using a groundwater model (MODFLOW-NWT) to assess the dynamics of a natural reservoir and groundwater interactions for both recharge and discharge scenarios for the reservoir. The outputs show the efficiency of a natural reservoir in enhancing soil saturation for the first 1-m level rise and working as an open water surface for the second meter which is useful to protect wetland habitats in the floodplain. The integrated model is envisioned to be a step toward sustainable management of the Drava floodplain.

References

1. Gumiero, B., Mant, J., Hein, T., Elso, J., Boz, B.: Linking the restoration of rivers and riparian zones/wetlands in Europe: sharing knowledge through case studies. *Ecol. Eng.* **56**, 36–50 (2013). <https://doi.org/10.1016/j.ecoleng.2012.12.103>
2. Dezső, J., Lóczy, D., Salem, A.M., Nagy, G.: Floodplain connectivity. In: Lóczy, D. (ed.) *The Drava River: Environmental Problems and Solutions*, pp. 215–230. Springer Science + Media, Cham, Switzerland (2019). https://doi.org/10.1007/978-3-319-92816-6_14
3. Habersack, H., Hein, T., Stanica, A., Liska, I., Mair, R., Jäger, E., Bradley, C.: Challenges of river basin management: Current status of, and prospects for, the River Danube from a river engineering perspective. *Sci. Total Environ.* **543**, 828–845 (2016)
4. Lóczy, D., Dezső, J., Czigány, S., Pirkhoffer, E.: Hydromorphological assessment of the lower Hungarian Dráva section and its floodplain. *Acta Geographica Debrecina Landsc. Environ.* **10**(3–4), 109–116 (2016)
5. Salem, A., Dezső, J., El-Rawy, M., Lóczy, D.: Hydrological modeling to assess the efficiency of groundwater replenishment through natural reservoirs in the hungarian Drava river floodplain. *Water* **12**, 250 (2020). <https://doi.org/10.3390/w12010250>.
6. Salem, A., Dezső, J., Lóczy, D., El-Rawy, M., Słowik, M.: Modeling surface water-groundwater interaction in an oxbow of the Drava floodplain. In: *Proceedings of the 13th International Conference on Hydroinformatics (HIC 2018)*, vol. 3, pp. 1832–1840, Palermo, Italy, 1–6 July (2018). <https://doi.org/10.29007/hb5d>
7. Niswonger, R.G., Panday, S., Ibaraki, M.: MODFLOW-NWT, a Newton formulation for MODFLOW-2005. *US Geological Survey Techniques and Methods 6-A37*, 44 pp. (2011).

8. Winston, R.B.: ModelMuse—a graphical user interface for MODFLOW—2005 and PHAST. U.S. Geol. Survey Tech. Methods. 6-A29, 52 pp. (2009).
9. Dezső, J., Salem, A., Lóczy, D., Słowik, M., Dávid, P.: Randomly layered fluvial sediments influenced groundwater-surface water interaction. In: Proceedings of the 17th International Multidisciplinary Scientific GeoConference SGEM 2017, <https://www.sgemviennagreen.org>. SGEM2017 Vienna GREEN Conference Proceedings, vol. 17, pp. 331–338, Vienna, Austria, 27–29 November (2017). ISBN 978-619-7408-27-0. <https://doi.org/10.5593/sgem2017H/33/S12.041>.
10. Salem, A., Dezső, J., El-Rawy, M.: Assessment of groundwater recharge, evaporation, and runoff in the Drava Basin in Hungary with the WetSpa model. *Hydrology* **6**, 23 (2019). <https://doi.org/10.3390/hydrology6010023>.