EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Hydrological Assessment of the Water Replenishment Possibility of the Uzh River Urbanized Floodplain on the Example of Bozdosky Park, Ukraine

Svitlana Velychko[1*], Olena Dupliak[1]

[1] Department of Water Supply and Sewage, Faculty of Engineering System and Ecology, Kyiv National University of Construction and Architecture, 31, Povitroflotsky Avenue, Kyiv, 03037, Ukraine
* Corresponding author's e-mail: velychko.sv@knuba.edu.ua

ABSTRACT

Over the last twenty years, the number of projects aimed at river restoration and rehabilitation increased significantly. In the city it is impossible to provide full river restoration, but at the same time it is possible to create a comfortable natural environment both for flora and fauna and for the citizens. In our work it was assessed the possibility of the floodplain restoration by the water replenishment of the dry old riverbed during the vegetation season on the example of the river inside the city. The simulation of the current state allowed to verify the main parameters of the model with the existing observations of the water levels in the river and lake and water levels in the wells located in the park. The several models of the river – floodplain interaction were simulated: floodplain was separated from the river by the flood control dyke, the water replenishment of the lake and the old riverbed was due to seepage (current state); the connection of the floodplain with the river by the culvert and the replenishment of the lake and the old riverbed with surface river water. The simulation showed that the lake isolated from the river is filled to a depth of not more than 0.5 m, the old riverbed is filled with water only during spring floods. The water balance calculations of the lake showed that in the conditions of isolation from the river, the lake volume is significantly affected by precipitation and evaporation from the lake water surface area. The connection of the lake with the river surface water significantly reduces the impact of the vertical components of the water balance, at the same time increases the seepage losses from the lake because of the water level raising. The connection of the river with the floodplain makes it possible to replenish the old riverbed and the lake in the mean year, but in the dry years the water level in the lake does not allow to replenish the old riverbed during the vegetation season. Calculations showed that to be able to keep the constant water level in the lake and old riverbed, it is necessary to increase the water level in the lake.

Keywords: water replenishment, river restoration, water balance, surface water, groundwater interactions, floodplain lake.

INTRODUCTION

From ancient times, people settled near the river, usually on the upper bank, or at the distance that provided protection during floods. Surface and groundwater were used for water supply, wastewater discharges, irrigation, and industrial development. Cities grew on both sides of the river, and the river was turned out in the centre of the city. With the population growth, the new areas were needed for construction and floodplains were actively urbanized. With the land cost increasing the flood control dykes were erected, which narrowed the floodplain and led to almost complete channelization of the river beds in the central parts of all major cities in Europe, Asia and North America. Until the 1980s, water management was mainly concerned with water transport, recreation, water supply, household and industrial needs, and flood protection [Wohl et al. 2015]. Such flood control management in order to protect the population led to changes in the landscape of river floodplains in urban areas.

The increasing pressure on the aquatic environment led to the significant deterioration of river water quality, the floodplain lakes drying and the species diversity decrease, which forced society to change its attitude to water management. Thus, since 2000, and especially after the implementation of the Water Framework Directive, the number of projects of the river restoration and rehabilitation were significantly increased. The analysis of river restoration projects for the period from 1989 to 2016, which were implemented in Europe, showed that after 2005 the number of river-floodplain restoration projects increased significantly and more than 50% of these projects were implemented at the expense of local communities, which indicates population support and necessity to improve the rivers ecological conditions [Szałkiewicz et al. 2018]. The river restoration projects occupy different areas, most projects were local on the small sections of the river or on the small streams and were implemented by various means: banks stabilization, riverbed clearing, widening the riverbed, restoration of meandering and multi-channels, connection the river with floodplain, restoration of the natural regime of water and sediment movement [Habersack et al. 2007, Fuller et al. 2021, Korpak et al. 2019]. In Ukraine the most river restoration projects related only to clearing the riverbed and restoring fish pits. The main problems limiting the implementation of river restoration projects are the high cost, especially for large-scale river and floodplain restoration projects, construction on the river banks and water use.

Now we have some experience of water replenishment of the floodplains outside residential areas, in the work by [Chen et al., 2020] presented the observations results of the replenishment impact on the Zhalong wetland (China), the biodiversity increased over 19 years, the assessment of water balance components showed that 64% of biomass growth was formed in the summer months due to precipitation, 25% due to water replenishment and 11% due to river flooding, the frequency of the water replenishment affected biodiversity. In the work by [Garrett-Walker et al. 2020] it was also emphasized that the biodiversity of the floodplain lake was affected by flooding intensity and the waterbody size, the biodiversity increased if the area of the lake was more than 1.0 ha and the lake perimeter was more than 800 meters. The observations of the water quality in the oxbow lakes, which were connected and isolated from the river, during the vegetation season were carried out by [Wang et al. 2020], the study showed that isolated oxbow lakes had higher concentrations of dissolved oxygen and nutrients, which led to eutrophication of the lakes, at the same time water quality significantly improved in lakes after the floods, which indicates the positive impact of the water replenishment. The authors [Seidel et al. 2017] carried out the study of aquatic biodiversity, which showed that oxbow lakes which permanently attached to the main river had significant potential for native species conservation. At the same time, during an extreme flood, bottom sediments were washed away and water turbidity, organic matter and nitrogen concentrations increased, which was a significant stress for aquatic organisms [Obolewski et al. 2018].

The river restoration projects face significant challenges related to the need to combine the natural environment and comfortable living on the urban area. In the work by [De Bell et al. 2020] it was assessed the restoration of the Medlock and Irk rivers (UK) in terms of biological and social indicators, which showed that from an ecological point of view, the states of the restored areas of the rivers were improved significantly. The social assessment of the restored areas was differed: citizens were pleased by natural river state, but demanded social infrastructure near the rivers and the preservation of historical heritage elements. The authors [Wanga et al. 2020] analyzed river restoration measures in China and on the example of the two mountain rivers in the city of Chongqing proposed the basic requirements for sustainable development of the aquatic environment in the city: clean water, green slopes, protection against flood and automated management system.

Thus, as evidenced by the authors' researches, the connection of the river with floodplain provides the more uniform replenishment without sharp flushing to support the local species biological conservation. It should be noted that the full river restoration in the urban area is impossible, but possible to create an urbanized natural environment that simultaneously provides protection from the floods and droughts, and satisfy the recreational and aesthetic needs of the population.

Assessment the interaction between the river and the floodplain lake is one of the key issues that need to be identified to determine the possibility of the floodplain replenishment. The various aspects of the interaction between surface water and groundwater were studied, in the work

[Kalbus et al. 2006] theoretical and empirical approaches were presented to assessing the interaction between surface water and groundwater. In the works [Salem et al. 2020, Li et al. 2019] the hydrological model based on the Darcy`s aquation was used to determine the relationship between the isolated lake and river water levels. The interaction groundwater - water levels in the channel was simulated based on the observations of the groundwater levels and water levels in the channel, and it was noted that seepage resistance increases significantly and the effect of channel level fluctuations on groundwater decreases in the presence of sediments in channel of 1,0 m thick [Koczka Bara et al. 2014]. In the work [Ha et al. 2008] it was used the semi-analytical solution to determine the interaction between the water level in the river and the groundwater level, the analysis showed that the higher the aquifer diffusivity the faster groundwater level responded to the river level changes. The change in the groundwater level was less noticeable if the flood hydrograph was short.

In the work [Lóczy et al. 2017] it was monitored the water replenishment of the oxbow lake and assessment of the water balance components. The full-scale hydrological monitoring was carried out and seepage losses were calculated, which showed that the lake, which hydrologically connected with river, could not store water for long period on the level higher than river water level. In the works [Golus et al. 2017, Dawidek et al. 2014] to assess the hydrological functioning of the floodplain lakes it was used the water balance method and identified its main components: precipitation, evaporation from the water surface, groundwater and surface water inflow and outflow. If the lake connected with river, the horizontal components of the water balance have much greater impact on the water storage of the lakes than the vertical ones, which remain almost constant. Therefore, the connection of a floodplain lake with a river will be the more effective method of water replenishment than irregular flushing during floods.

In our work, the part of the Uzh River (Ukraine) within the Bozdos Park in the center of Uzhgorod was studied. Over the last twenty years, climate change led to the average annual temperatures increasing in the Carpathians, the summer became hotter, which affected the distribution of the river runoff and limited runoff of the Carpathian rivers [Kanarskyi 2016].

Fig. 1. The Uzh River within the city of Uzhgorod, September 2019

Estimation of the minimum runoff fluctuations of the Uzh River, performed by [Obodovsky et al. 2018] is testified that despite the higher water phase of the minimum runoff, very low water levels in the rivers and shallowing of floodplain lakes were observed. The same trends were observed on the Uzh River, the figure 1 presents the Uzh River within the city of Uzhgorod. The floodplain water replenishment in the area of the park during the dry season would create a favourable environment for the flora and fauna of the park and the additional recreational area for citizens.

The water replenishment of the floodplain in combination with the recreational infrastructure development will lead to aesthetic and sensory improvement of urban space, will make the natural environment more accessible, which will have a positive impact on the social environment. In the context of increasing urban tension, the development of natural areas in the cities is an urgent task that will provide double environmental and social benefits.

The purpose of the work was to simulate the existing conditions of the riverbed-floodplain interaction and to assess the possibility of water replenishment of the floodplain lake and old riverbed on the territory of the Bozdosky Park in urban environment.

MATERIALS AND METHODS

Study area and low water

The Uzh River belongs to the basin of the Tisza River, the source is located in the Transcarpathian region at the altitude of 970 m, flows into the river Laborec in Slovakia. The length of
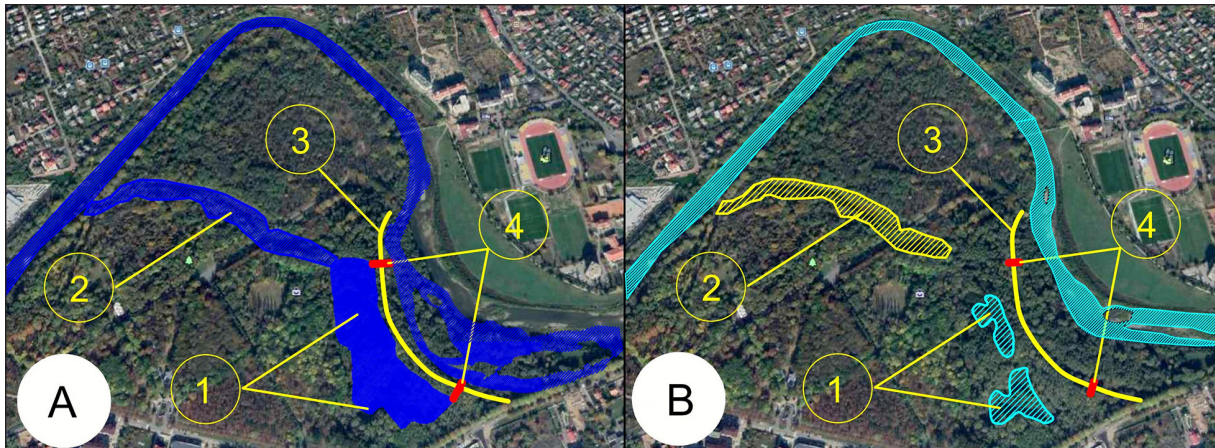
Fig. 2. Study area: A – design state of the park; B – current state of the park; 1 –
lake, 2 – old riverbed, 3 – dyke, 4 – pipes for water replenishment

the river is 107 km on the territory of Ukraine, the catchment area is 1970 km², the average slope in the project area is 0.00076. The study considers the lower part of the Uzh River, located in the Transcarpathian lowlands in the Uzhgorod city. In ancient times, the central part of the city was crossed by three distributary channels of the Uzh River, which meandered freely along a wide floodplain. In 1923, river regulating work began on the Uzh River within the city. The alone distributary channel was left and the floodplain area was isolated by flood control dykes, designed to protect against flooding of 10% probability (return period of 10 years). In 1954, Bozdosky Park was laid out inside the loop of the river, in which the water replenishment of the old riverbed was restored. Under the design conditions, the lake and the old riverbed were connected to the main river, due to which the water exchange in the lake and old riverbed took place (Fig. 2A). After the extreme flood, the riverbed changed direction slightly, deviating to the right, and sediments began to be deposited along the flood control dyke. Now, the connection between park and the Uzh River is lost, there is no water in the old riverbed, two small lakes were formed, they are silted up, covered with woody and shrubby vegetation, which almost completely blocked access to the lakes (Fig. 2B). The area of lakes has significantly decreased: it is less than 1 ha during the dry season, the water depth is 0.4 m in the lakes.

The mean annual flow of the Uzh River is 29.6 m3/s in the project area. The largest runoff occurs in spring or winter, the lowest runoff is formed in the period of August – October in the dry year.

The winter low water period is interrupted by rain floods, so the runoff in winter is much higher than in summer and autumn [Obodovsky et al. 2018]. The typical years with the stable summer-autumn low water period were taken using the real year method to simulate hydrological river regime. In 2003 (95% probability) the winter was frosty with low snow, spring floods were low due to the lack of significant precipitation, low water period lasted from June to September. In 2002 (75% probability) the spring floods started in February, the low water period lasted from July to September. In 1999 (50% probability) the floods started in March and they were higher due to melting snow and heavy rains, low water period was short and occurred in September.

Study methods

Topographic maps of 1975, 1995 and 2019 at the scale of 1: 2000 were used to compare the position of the Uzh riverbed. The water levels were calculated for the cross sections made each 140 m from Uzhhorod hydrometric station to bridge near the park. The cross-section of the Uzhhorod hydrometric station, located at a distance of 2.1 km above the park, was taken as the base. Based on the Q-h curve constructed for the hydrometric post, Manning's coefficients characterizing riverbed and bank roughness were determined. The roughness coefficient is 0.022 for dry and mean years.

The meteorological data (temperature, wind speed, precipitation) for certain years were accepted according to the Uzhhorod climate station.

The evaporation from the water surface in the ice-free period was calculated using the method described in the work [Velychko et al. 2021]:

$$E_0 = 0.37n(1 + 0.14u_{200}) \cdot (e_0 - e_{200}) \quad (1)$$

where: E_0 – evaporation from the water surface in the ice-free period, m; e_{200} – mean value of water vapor elasticity on the height of 200 cm up the water surface, mbar; u_{200} - mean wind speed over the drying beds at the height of 200 cm, m/s; e_0 – maximum elasticity of water vapor, mbar; n – time period, day.

The soil data were taken from 13 wells with the depth of 10-24 m, which were located on the banks of the Uzh River, near lake and along the old riverbed. The groundwater levels on the park area were located at a depth of 0.5 - 6.3 m, determined on the basis of water level measurements in wells during dry season. The hydraulic conductivity in water-saturated soils were obtained based on the results of field research conducted in August-October 1988. From the top, under the fertile soil, the floodplain is covered with the thin layer of silty loam with pebbles and gravel inclusion (15 to 25%) with the depth of 1.5 m, the saturated hydraulic conductivity is 0.2-1.0 m/day. There is gravel-pebble soil with loamy and clay aggregate at the depth below 1.5 m, the saturated hydraulic conductivity is 30-50 m/day. The aquitard was not detected at the depth of 24 m. The calculated value of the hydraulic conductivity was determined by selecting during the current state simulation of the lake and comparing the results with water levels in the river, lake and groundwater in the park according to survey data.

The floodplain is isolated from the river by the flood control dyke, the territory of the park near the lake was raised to the level of the 10% flood flow. The water levels fluctuations in the river are 107.6-108.5m near the lake in the low water period, during the spring floods the water level rises to 110.2 m. The bottom level of the lake is 107.5 m. The lake is hydraulically connected to the Uzh River. The lake is fed by the groundwater flow. The movement of the seepage flow is directed from the upstream of the river to the downstream and occurs in the gravel-pebble soil (Fig. 3).

The position of the water level in the lake (current state) in the ice-free period (March-October) was determined by the water balance method, taking into account the seepage inflow to the lake from the river when the water level rises, the seepage loss from the lake and vertical components of the water balance: precipitation on the surface of the water and evaporation from the water surface:

$$\Delta W = P \cdot f - E_0 \cdot f + SI - SO \quad (2)$$

where: ΔW – change in storage, m³; P – precipitation, m; f – lake area, m²; SI – seepage inflow from river, m³; SO – seepage outflow into the downstream, m³.

When the direct connection between the lake and the surface river water is installed, the components of the river runoff are added to the water balance according to the equation:

$$\Delta W = P \cdot f - E_0 \cdot f + SI - SO + RI - RO \quad (3)$$

where: RI – river inflow through the intake structures, m³; RO – river outflow through the channel, m³.

The seepage flow into the lake and seepage losses to the downstream were calculated by equation:

$$SI(SO) = K\frac{L}{d}(H_1^2 - H_2^2) \quad (4)$$

where: K – hydraulic conductivity, m/s; d – distance between river and lake, m; L – seepage length, m; H_1, H_2 – water level in the river and lake, m.
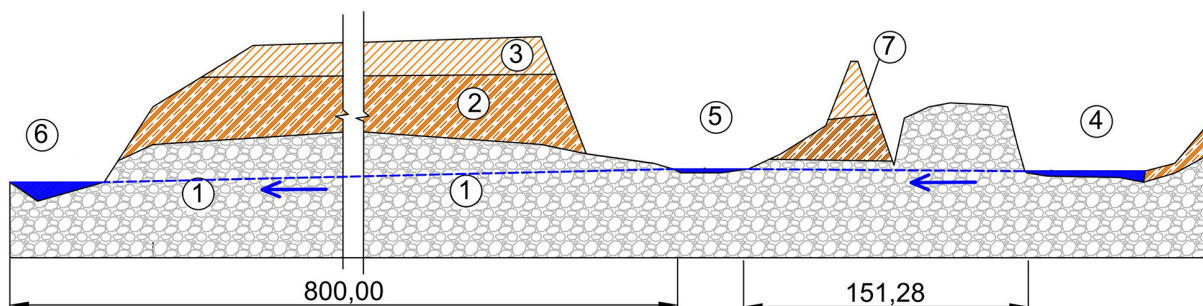

Fig. 3. Calculation schema, current state: 1 – gravel - pebble soil; 2 – silty loam with gravel - pebble inclusion; 3 – loam with sand layers; 4 – upstream of the Uzh River; 5 – lake; 6 – downstream of the Uzh River; 7 - dyke

The culvert was taken as the water intake structure. The discharge was calculated by equation:

$$Q = \varphi w_c \sqrt{2g(H_1 - H_2)} \qquad (5)$$

where: Q – water discharge, m³/s; φ – velocity coefficient; w_c – flow area, m²; H_1, H_2 – water head at the entrance and outlet of the intake structure, m.

The water intake structure supplies water from the river to the lake during the low water period. The water intake is closed by the gate to prevent getting turbid water and debris from the river to the lake and to preserve local biodiversity during an extreme flood.

RESULTS AND DISCUSSION

Today the level of the lake bottom is 107.5 m, and the level of the old riverbed bottom is 108.0 m according to the topographic survey. Therefore, in order to replenish the park and to keep water exchange, the water level in the river must exceed the bottom of the old riverbed or the water level in the lake must be higher than 108.0 m to overflow water into the old riverbed during the low water period.

The analysis of water level fluctuations showed a significant irregular runoff distribution in the mean year and dry years in the Uzh River. The maximum water levels occur in winter and spring during floods. The minimum water levels were observed in the summer months and at the beginning of the autumn. The water levels calculation showed that the water levels in the summer months did not exceed the level of 108.0 m during the low water period, only

rain floods briefly increased the water levels in the river. The rain floods could occur several times in summer depending on the mereological condition of the year, but high-water levels did not last more than 1-2 days.

In modern conditions there is no connection of the lake and the old riverbed with the river surface waters, the water replenishment into the lake is due to precipitation on the water surface and seepage through the base of the dyke in the hyporheic zone. The high hydraulic conductivity in the alluvial deposits allows the intensive water exchange between the lake and the river, the lag time of water levels in the lake does not exceed 14-20 hours. At the same time, the simulation showed that the losses for soil saturation in the unsaturated zone leads to decrease of the groundwater amplitude and seepage inflow to the lake. The maximum water levels in the lake occur in spring, which is due to the melting of winter precipitation and spring floods in the Uzh River (Fig. 4-6).

Summer floods and rains slightly increase the groundwater levels and the accumulation of water in the lake due to high hydraulic conductivity of gravel and pebble soil in the hyporheic zone. But summer floods are short: the rise and fall of levels occurs during 30 hours, most precipitation is spent on seepage through unsaturated soil, which reduces the seepage inflow into the lake (Fig. 4-6). The maximum water levels do not exceed 108.00 m in the lake during dry season in the mean year, the depth in the lake is at the level of 30 cm in dry years. The lake area is less than 1.0 ha in the low water period. Since the old riverbed is fed due to seepage flow from the river and the lake, the water does not enter
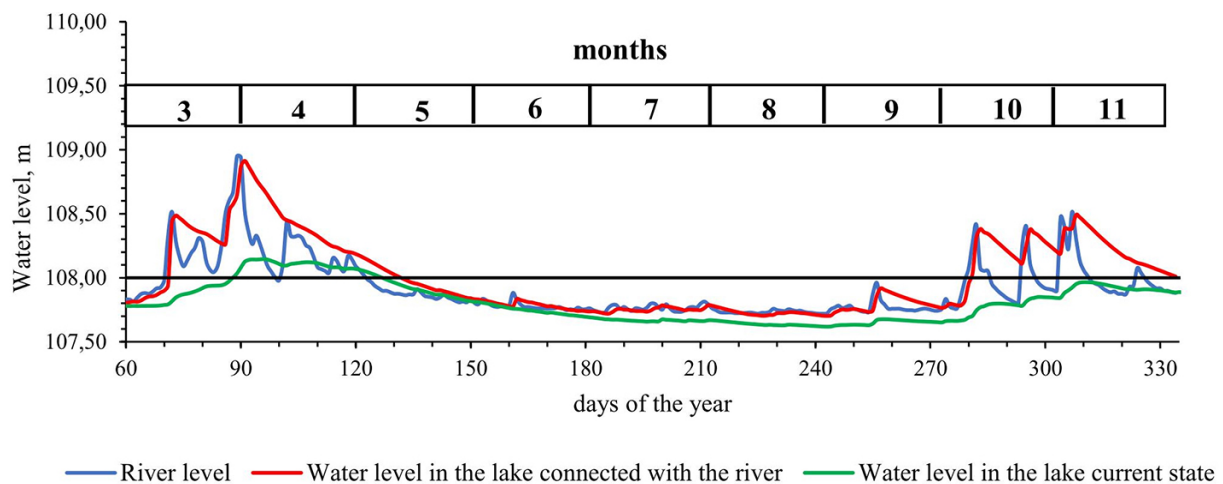

Fig. 4. The water level fluctuations in the river, lake during the dry year of 95% probability
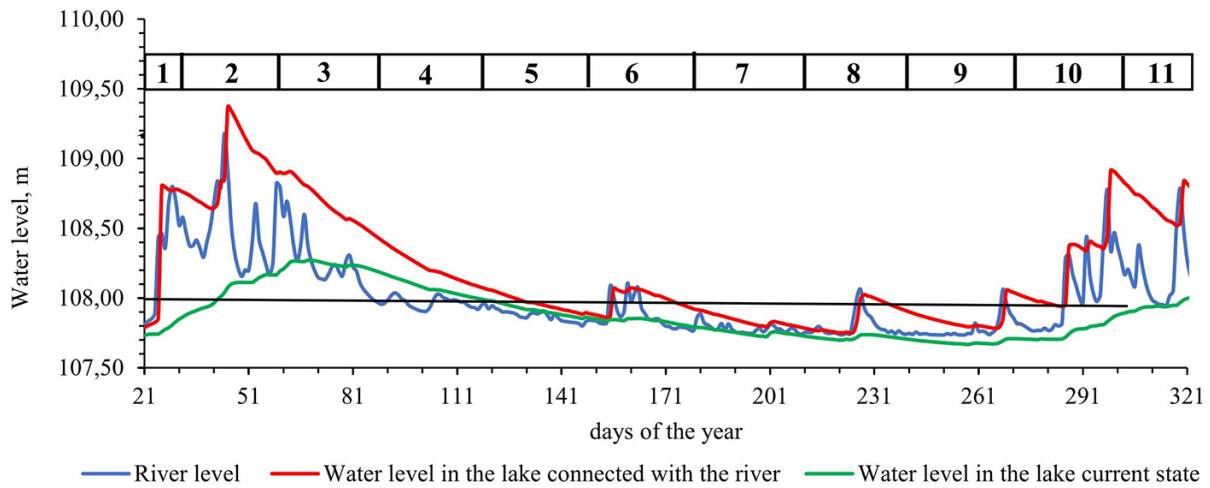
Fig. 5. The water level fluctuations in the river, lake during the dry year of 75% probability
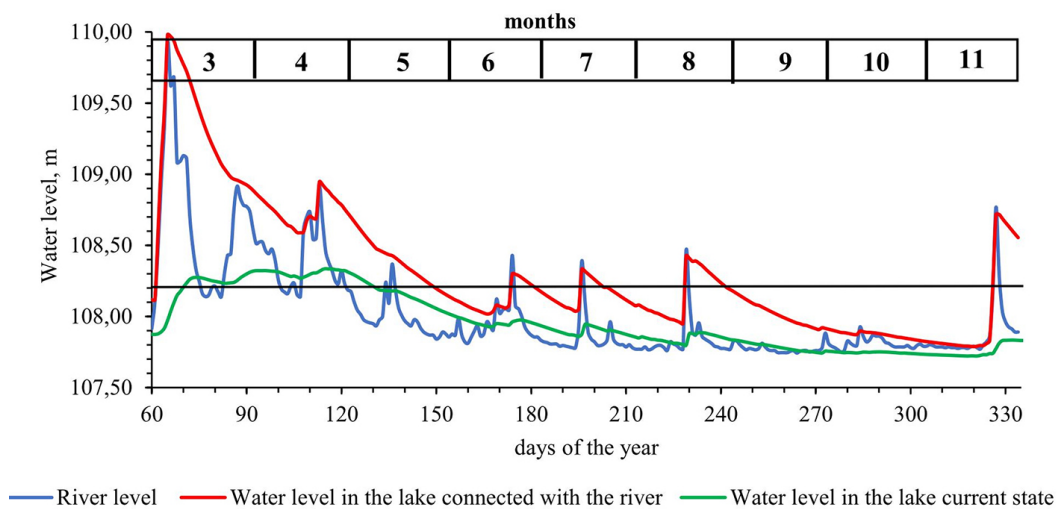

Fig. 6. The water level fluctuations in the river, lake during the mean year of 50% probability

the old riverbed which remains dry almost all year when the water level in the lake is lower the 108.00 m, except spring floods.

The connection of the lake with the river by culvert provides more intensive watering of the park: the water levels in the lake almost always are above 108.00 m and range from 108.00 -108.40 m in the vegetation season of the mean year. Thus, the water level can be maintained at 20-30 cm above the bottom of the old riverbed. But for dry years with low water levels in the river, the connection between the lake and the river does not provide sufficient water levels in the lake and old riverbed.

As water level in the river fall and flood water does not inflow into the lake, the seepage losses in the lake increase, which does not allow to store

water in the lake for a long time. The maximum seepage losses take place in the spring during the sharp level falling in the river and reach 1214 m³/day. The maximum seepage losses are 411 m³/day in the dry period between summer floods, which is due to the lower seepage pressure. But even relatively small seepage losses allow to maintain higher water levels in the lake, but do not allow to ensure the constant water flow into the old riverbed and water replenishment of the park.

As the water balance components diagram shows (Fig. 7), in the isolated lake the vertical components of the balance (precipitation (P) and evaporation (E)) significantly affect the water storage in the lake and are comparable with horizontal components (seepage from river (SI) and seepage losses into the downstream (SO)).
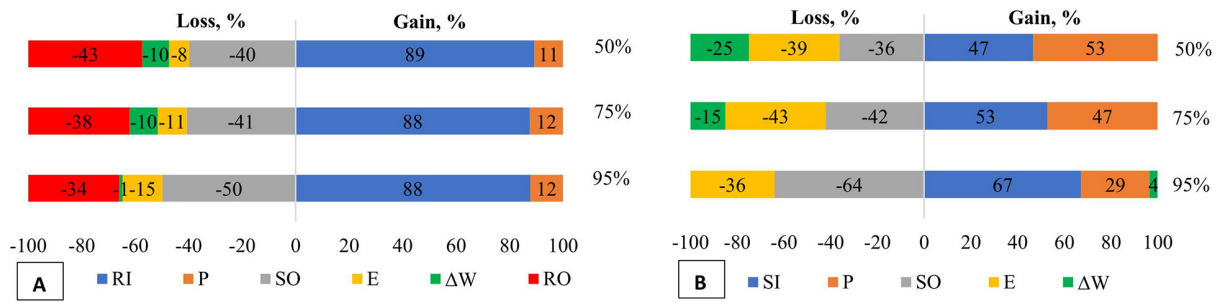
Fig. 7. The water balance components: A – the lake connected with river; B – the isolated lake

If the lake is connected to the river, the impact of the vertical components decreases, they have less effect on the water storage, due to increased surface runoff (*RI*) through the culvert, which almost equalizes river and lake water levels during 24 hours. The seepage losses increase slightly due to seepage pressure increasing into the downstream and seepage into the river when water level falls in the river. When the water level in the river falls, the free inflow into the lake is accepted zero, it is assumed that the gate on the culvert is closed during this period, and water flows into the old riverbed for its replenishment (*RO*).

The connection of the lake with the river allows to maintain more natural mode of water level fluctuation and water quality in the lake, and provides spring flushing of the lake and old riverbed. Maintaining the constant water level in the old riverbed can be achieved by gate operating at the culvert between the lake and old riverbed, but due to the low water level in the lake and the significant seepage losses which is more than 50%, the water level in the old riverbed is not exceed 20 cm in summer and autumn.

CONCLUSIONS

The realization of the full river restoration projects is not possible on the urban area, but it is possible to create an artificial environment similar to the natural state, by partial water replenishment of the floodplain in the green zones of the city.

In current conditions, when the lake is isolated from the river, climatic conditions (evaporation and precipitation) significantly affect the water accumulation in the lake. Replenishment and flushing of the lake occur only in the wet years, when there are extreme floods take place, which often occur in the cold period and cannot provide watering of the territory during the vegetation season. In addition, extreme floods bring sediments and debris from the mountainous part of the Uzh River, which settle in the park area. To ensure the proper sanitation of the lake in the park, the extreme flood flow through the lake should be avoided by closing the gate and passing the flood flow directly from the river through the old riverbed bypassing lake.

The simulation of the current state of the lake allowed to determine the average hydraulic conductivity of the alluvial deposits, it is 19.8 m/day. Due to the high hydraulic conductivity of the hyporheic zone, the depth of the water is 0.5-0.3 m in the isolated lake. But low water levels in the river allow to create the volume of the lake of 11.0-16.0 thousand m³ in the summer-autumn period. It is possible to increase the water depth and volume of the lake to 30 thousand m3 only by deepening the lake, but lake clearing will still not allow water to flow into the old riverbed, the bottom of which is located at 108.0 m.

The connection of the lake with the river changes the ratio of horizontal and vertical components of the water balance and the impact of evaporation and precipitation on the lake is significantly reduced. But replenishment of the lake with surface water leads to a rapid increase in the water level in the lake during the flood and an increase in seepage pressure, which in turn increases seepage losses, and after falling the water level in the river, the water level in the lake also falls sharply. Therefore, the water accumulation for the dry period only by spring floods is not enough. Only in wet years with frequent floods in summer and autumn it is possible to ensure the accumulation of water in the lake and regular discharge it into the old riverbed.

The connection of the lake with the river and clearing the lake increases the volume of water accumulated during floods to 55.0-69.8 thousand m³ and allows to water flow into the old riverbed during the mean year. In the dry years, when the river levels do not exceed 108.00 m, it is not

possible to provide watering the old riverbed in the summer-autumn period.

To maintain water in the lake with the depth of 3.0 m and ensure the flow into the old riverbed in the summer-autumn period of the dry year, the existing water levels in the river are not enough. It is necessary to rise the water levels in the lake to the level of 109.8–110.00 m, which will create the useful volume of 160–170 thousand m³ for water replenishment of the park in low water period. It is possible to increase water levels in the low water period by creating backwater in the river, which will provide a significant increase in the capacity of the lake and permanent water level in the old riverbed.

REFERENCES

1. Wohl E., Lane S.N., and Wilcox A.C. 2015. The science and practice of river restoration, Water Resources Research, 51, 5974–5997.

2. Szałkiewicz E., Jusik S., Grygoruk M. 2018. Status of and Perspectives on River Restoration in Europe: 310,000 Euros per Hectare of Restored River, Sustainability, 10(1), 129, 15 p.

3. Chen L., Liu S., Wu Y., Xu Y., Chen S., Pang S., Gao Z., Zhang G. 2020. Does Ecological Water Replenishment Help Prevent a Large Wetland from Further Deterioration? Results from the Zhalong Nature Reserve, China. Remote Sensing, 12, 3449.

4. Habersack H., Piégay H. 2007. 27 River restoration in the Alps and their surroundings: past experience and future challenges, Developments in Earth Surface Processes, Elsevier, 11, 703-735.

5. De Bell S., Graham H., White P. 2020 Evaluating Dual Ecological and Well-Being Benefits from an Urban Restoration Project, Sustainability, 12 (2), 695.

6. Wanga Y., Liub X., Huc W. 2020. The research on landscape restoration design of watercourse in mountainous city based on comprehensive management of water environment, European journal of remote sensing, 11p.

7. Wang D., Li Z., Li Z., Pan B., Tian S., Nie X. 2020 Environmental gradient relative to oxbow lake-meandering river connectivity in Zoige Basin of the Tibetan Plateau, Ecological Engineering, 156, 105983.

8. Garrett-Walker J., Collier K., Daniel A., Hicks B., Klee D. 2020. Design features of constructed floodplain ponds influence waterbird and fish communities in northern New Zealand, Freshwater Biology, 65(12), 2066-2080.

9. Fuller I., Death R., Garcia J., Trenc N., Pratt R., Pitiot C., Matos B., Ollero A., Neverman A., Death A. 2021. An index to assess the extent and success of river and floodplain restoration: Recognising dynamic response trajectories and applying a process-based approach to managing river recovery, River Research and Applications, 37(2), 163-175.

10. Seidel M., Voigt M., Langheinrich U., Hoge-Becker A., Gersberg R., Arevalo J., Luderitz V. 2017. Re-connection of Oxbow Lakes as an effective measure of river restoration, Clean-Soil Air Water, 45(3), 1600211.

11. Obolewski K., Glińska-Lewczuk K., Bąkowska M. 2018. From isolation to connectivity: the effect of floodplain lake restoration on sediments as habitats for macroinvertebrate communities, Aquatic Sciences, 80, 4.

12. Korpak J., Lenar Matyas A. 2019. Stream channel changes as a result of sudden sediment release due to check dam lowering (Polish Carpathians), Environmental Earth Sciences, 78, 14, 404.

13. Obodovskyi O., Surai K., Pochaevets O. 2018. Estimation of the minimum water runoff of the Uzh sub-basin (Tysza river basin), Hidrolohiia, hidrokhimiia i hidroekolohiia, 2(49), 6-15.

14. Kanarskyi Yu.V. 2016. Climate changes in the region of Ukrainian Carpathians at the beginning of XXI century and its influence on the biodiversity. Scientific principles of biodiversity conservation, 7(14), 1, 15-36.

15. Velychko S., Dupliak O. 2021. Assessment of the Influence of Evaporation and Evapotranspiration on the Volume of Sludge Accumulation in the Sludge Drying Beds, Journal of Ecological Engineering, 22(2), 63–69.

16. Kalbus E., Reinstorf F., Schirmer M. 2006. Measuring methods for groundwater – surface water interactions: a review, Hydrol. Earth Syst. Sci., 10, 873–887.

17. Salem A., Dezs J., El-Rawy M., Lóczy D. 2020. Hydrological Modeling to Assess the Efficiency of Groundwater Replenishment through Natural Reservoirs in the Hungarian Drava River Floodplain, Water, 12, 250.

18. Li Y., Zhang Q., Lu J., Yao J., Tan Z. 2019. Assessing surface water–groundwater interactions in a complex river-floodplain wetland-isolated lake system, River Res. Applic. 35, 25–36.

19. Koczka Bara M., Velísková Y., Dulovičová R., Schügerl R., 2014, Influence of surface water level fluctuation and riverbed sediment deposits on groundwater regime, J. Hydrol. Hydromech., 62, 3, 177–185.

20. Ha K., Koh D., Yum B-W., Lee K-K., 2008. Estimation of river stage effect on groundwater level, discharge, and bank storage and its field application, Geosciences Journal, 12(2), 191-204.

21. Lóczy D., Dezső J., CzigányS., Prokos H., Tóth G. 2017. An environmental assessment of water replenishment to a floodplain lake, Journal of Environmental Management, 202(2), 337-347.

22. Golus W., Bajkiewicz-Grabowska E. 2017. Water circulation in the moraine ponds of northern Poland, Hydrobiologia, 793, 55–65.

23. Dawidek J., Ferencz B. 2014. Water balance of selected floodplain lake basins in the Middle Bug River valley, Hydrol. Earth Syst. Sci., 18, 1457–1465.