FLOOD TRANSFORMATION EFFECT OF A SYSTEM OF SMALL WATER RESERVOIRS

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Abstract

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The paper resumes the investigation of transformation of watershed flow off caused by retention volumes of small water reservoirs (SWR) in landscape. Based on our work experience in the field of water reservoir design and research, we know that simple system of even small fishponds disposes of nonnegligible free retention volume. We decided to verify this assumption with aid of exact determination of discharge transformation within the basin containing realized system of small water reservoirs. The input water management data for design of water reservoirs are represented by water discharge in existing stream related to the point of designed SWR. In the Czech Republic, the data are provided by the Czech Hydrometeorological Institute (CHMI), however the data refer to an unaffected discharges, i.e. without consideration of transformation effects of existing small water reservoirs within the basin. Although the total available volume for transformation purposes of investigated SWR system is relatively small, the results show the transformation effect of such reservoirs is not insignificant. Furthermore the transformation effect is raised by proper design and functionality of the whole system of water reservoirs.

Keywords: basin, discharge transformation, fishpond, IDF curve, rainfall-runoff modelling, runoff curve number

INTRODUCTION

Actual determination of water discharges, which are related to the frequency of occurrence according to the standard specification ČSN 75 1400 Hydrological data on surface water (ČSN 75 1400), result from unaffected flow off from the watershed. These fundamental hydrological data are usually determined on the basis of straight measurements inside water courses with operated hydrometric profiles (WMO, 2008). On the contrary, the discharges of small streams without regular measurement facilities are usually derived from hydrological analogy (Krešl, 2001). The data are instrumental in calculation of flow capacity of hydrotechnic structures relied to the water reservoir operation (Šlezingr, 2013; Šlezingr, Fialová, 2012; Vrána, 1998), e.g. spillways and outlets – ČSN 75 2410 Small water reservoirs.

Today, fishponds are often constructed in order to generate the water reservoir system. Thus the system provides certain retention capacity in basin.

MATERIALS AND METHODS

The investigated locality is situated within cadastre Potstat nearby military area Libava (Czech Republic). The enclosure profile of studied watershed lies on Boskov stream, 400 m above junction with Velicka river (a part of watershed No. 4-11-02-0370). The watershed falls into Odra highlands with altitude of 502–621 m a.s.l. and mean slope of 7.83%. The total area is 5 km². The locality could be characterized as woody-agricultural landscape of late medieval settlement.

The research workflow involved collecting miscellaneous data related to the watershed (natural and hydrological conditions, land use, technical parameters of water reservoirs), building-up transformation model for particular water reservoirs and overall model processing related to the transformation of flood discharge through the system of three small water reservoirs (SWR Deml, Potstat, Starý rybník).

The water reservoirs were designed with software AutoCAD Civil 3D, which is a comprehensive software suite for project preparation and management, and supports a wide range of civil engineering tasks. The application's program code is based on an object-oriented architecture. Thanks to this, dynamic relations exist between the individual project entities, which means, that related objects are properly updated after any modification (Autodesk, 2009). The software was also used for the bathymetry analysis of water reservoirs (water levels due to swamped volumes). The SWR Potstat was built-up in 2009, Deml was realized in 2013 and Starý rybník is presently under construction.

The hypsographical data of basin were represented by contours of ZABAGED (Geographical Data Base of the Czech Republic). The digital elevation model (DEM) of watershed was worked out with software ESRI ArcGIS Desktop. Consequent data processing in ArcGIS involved the delineation of particular watersheds. These ones were defined by the dikes of investigated water reservoirs as enclosure profiles of new subbasins (Fig. 1). Further analysis contained the computation of all subbasin parameters (area, slope, talweg length, etc.). The method of runoff curve numbers was used for the derivation of incident flow off. The model is intended for calculation of the direct runoff from watershed caused by storm rainfall. The direct runoff covers surface and hypodermic runoff. The ratio of the components of overall runoff is represented by numbers of runoff curves (CN). Furthermore, CN is the probability indicator of runoff type. The higher the CN, more probable the direct runoff is related to the surface runoff (Janeček *et al.*, 2008).

Runoff curve numbers (CN) were derived from land use (Janeček *et al.*, 2008; Markovič *et al.*, 2014), from hydrological conditions and main soil units (evaluated soil ecological units available at Czech Survey and Cadastral Bureau website).

Rainfall-runoff processes were modeled in software Hydraflow Hydrographs Extension for AutoCAD Civil 3D. The software supports hydrological computational methods based on SCS unit hydrograph (TR-20, TR-55) and rational

1: *Layout of watersheds (W1–W4) with enclosure profiles – dikes of water reservoirs*

methods (Autodesk, 2013). The peak flow for the unit hydrograph is computed using the equation (1).

$$Q_p = \frac{484 \times A \times P}{T_p}, \tag{1}$$

A [km²] .... basin area,
P [mm] .... total excess precipitation,
T_p [hrs] .... time to peak.

The time to peak (T_p) and the time base (T_b) values determine the characteristics of the unit hydrograph. Time of concentration is calculated via equation (2).

$$T_c = 1.67 \times \frac{L^{0.8} \times (S + 1)^{0.7}}{1900 \times I^{0.5}}, \tag{2}$$

L [m] .... hydraulic length,
I [%] .... basin slope,
CN [–] .... curve number,
S = (1000/CN) – 10.

Intensity, duration and frequency rainfall curves (IDF) were derived from the data of short-term rainfall events collected by J. Trupl (Trupl, 1958). The output of the software is represented by set of hydrographs related to the particular watersheds and overall basin.
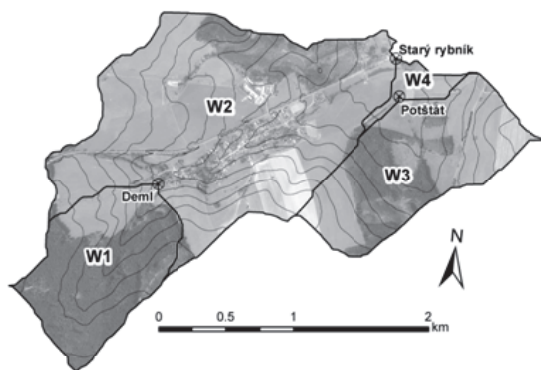
The model of reservoir transformation effect was carried out in Microsoft Excel. The computation is based on given hydrograph for particular watershed related to the chosen rainfall event, known reservoir bathymetry and construction parameters of outlet and spillway. The resulting hydrograph represents the transformed discharge from reservoir.

RESULTS

The overall watershed was split into four subbasins W1–W4 due to the layout of considered water reservoirs and stream network for which the total area, average slope and CN values were calculated.

Considered rainfall intensities are related to the rain event duration 15, 20, 30 and 60 minutes with frequency of 100 years. The duration values are related to the hypothesis that the main transformation effect of fishponds (reservoirs with low retention volume) is expected during short-term rainfall events. The frequency of rainfall event was chosen with respect to the fact that many water management measures and structures are designed assuming this value.
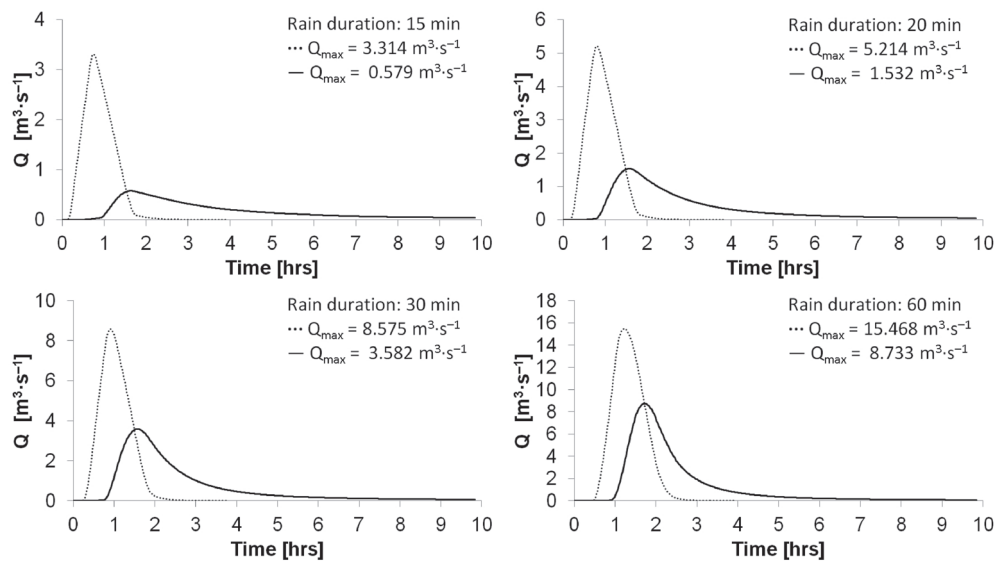
The system of small water reservoirs consists of the three fishponds (SWR Deml, Potstat and Starý rybník) for which the crucial volumes were calculated. The sum of maintainance and storage volumes relies on the level of outlet edge (Hanák *et al.*, 2008; Tlapák *et al.*, 1992). Controlled retention volume (V_{ro}) refers to the level of spillway edge and uncontrolled retention volume (V_{rn}) is related to the maximum designed water level in reservoir due to the project documentation. The input data are presented in Tab. I.

I: *Input data*

|	Watershed				Rainfall events			Small water reservoir system				
Label	A [km²]	I [%]	CN	Enclos. prof.	I [cm·hr⁻¹]	D [min]	F [yr]	Name	V_s+V_z [m³]	V_{ro} [m³]	V_{rn} [m³]	V_{tot} [m³]
W1	1.00	7.16	71	Deml	11.9	15	100	Deml	9990	0	2070	12060
W2	2.74	8.52	77	Starý rybník	10.2	20	100	Potštát	13600	0	4550	18150
W3	1.13	7.09	75	Potštát	8.1	30	100	Starý rybník	51880	4270	20540	76690
W4	0.13	4.42	70	Starý rybník	5.2	60	100	V_s…maintainance volume; V_z…storage vol.;				
Overall	5.00	–	–	Starý rybník				V_{ro}…controlled retention vol.;				
A…area; I…∅ slope; CN…∅ curve number					I…intensity; D…duration; F…frequency			V_{rn}…uncontrolled retention vol.; V_{tot}…total volume				

2: *Runoff hydrographs – final enclosure profile (Starý rybník)*

The particular hydrographs were modeled for both subbasin and overall watershed for each rainfall event without application of the transformation effect of water reservoirs (i.e. no reservoirs exist). After computing the excess precipitation hyetograph, the direct runoff hydrograph using the concept of convolution or linear superpositioning was computed. Each increment of the design storm hyetograph was multiplied by each ordinate of the unit hydrograph. The resulting hydrographs were then added or superimposed to obtain a final runoff hydrographs. Consequently the hydrographs were recomputed with involvement of transformation effect of the water reservoir system – final enclosure profile Starý rybník (Fig. 2).

The transformation effect of fishponds is mainly caused by the operational adjustment of retention volumes in the reservoir and construction of outlet and spillway. The outlets of Deml and Potstat were constructed as sluices when the damming is ensured by double wall of timber sluice planks with clay sealing. Deml and Potstat are equipped with emergency crest spillways (Fig. 3). Combined hydrotechnic structure ensures the function of outlet and spillway on the Starý rybník reservoir.

The computations of transformation by water reservoir contain the amount of water outflow through the hydrotechnic structures (outlet and spillway) with respect to the amount of water inflow into the reservoir.

During the investigated rainfall event, at first the water table inside reservoir reaches the upper level of sluice planks in outlet. The overflow rate calculation assumes the rectangle-shaped flow space with effect of side contraction and varying overflow discharge coefficient (m) depending on
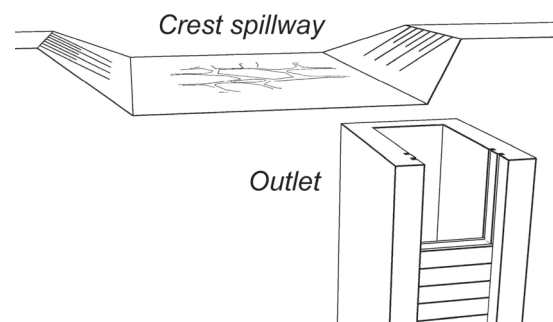
3: *Hydrotechnic structures of water reservoirs related to the transformation effect*
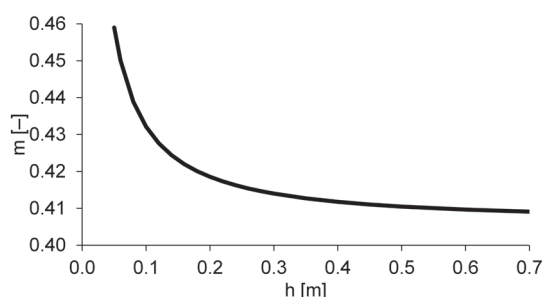
4: *Overflowing discharge coefficient (m) for cutting-edge conditions depending on the height of overflowing water table (h)*

the height of overflowing water table – equation (3). The height of overflowing water table continually increases, so the conditions of overflow through the wide crest, narrow crest and cutting-edge can occur due to the dimensions of double sluice plank wall inside outlet structure (Fig. 4). Thus the discharge coefficient also varies within the range of approximately 0.32–0.46 (Synková, Zlatuška, 2003).

$$Q_o = m \times b \times \sqrt{2g} \times h^{\frac{3}{2}}, \tag{3}$$

m [–] .... overflow discharge coefficient,
b [m] .... overflow edge length assuming side contraction,
g [m·s⁻²] .... acceleration of gravity,
h [m] .... height of overflowing water table,
Q_o [m³·s⁻¹] ... overflow rate – outlet.

By the time the water table reaches the level of the spillway edge, the overflow via spillway structure begins. The governing equation (4) is introduced below. The discharge coefficient (m) corresponds to the construction dimensions of spillways. Conditions of wide crest occur in the case of crest spillway (Deml and Potstat water reservoir). Conditions of wide and narrow crest occur on the spillway of Starý rybník reservoir during the overflow through combined hydrotechnic structure.

$$Q_s = m \times b \times \sqrt{2g} \times h^{\frac{3}{2}} + \frac{8}{15} \times \mu \times \sqrt{2g} \times \cot\alpha \times h^{\frac{5}{2}}, \tag{4}$$

µ [–] .... splay coefficient of spillway side,
α [°] .... slope of spillway side,
Q_s [m³·s⁻¹] ... overflow rate – spillway.

Resulting immediate discharge from the reservoirs is given by the sum of outlet and spillway overflow rate. The transformation effect of particular water reservoirs is related to the parameters of certain rainfall event, available free volume inside reservoir and parameters of hydrotechnic structures. In addition, the overall transformation effect of water reservoir system is dependent on the basin characteristics, adjustment of reservoirs within the whole watershed and their cooperation on the field of transformation during the rainfall-runoff
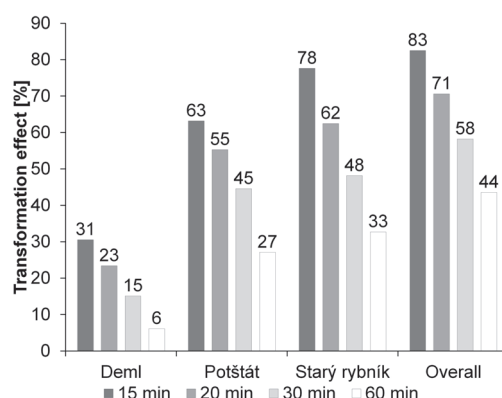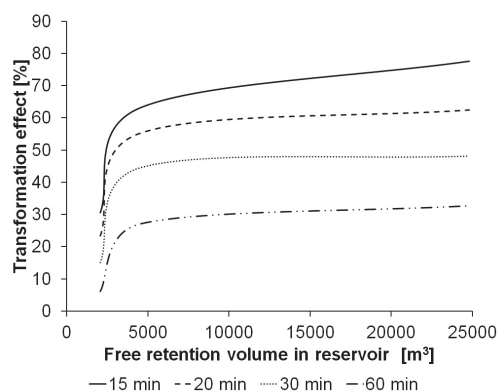

5: *Transformation effect of water reservoirs due to the rainfall event duration (15–60 min)*

process. We can usually use only controlled and uncontrolled retention volume for the purposes of discharge transformation in the case of fishponds. The limitation is given by their primary function – fish farming with demand for fixed steady water depth.

Fig. 5 shows, that the transformation effect of investigated reservoirs generally decreases with increasing duration of rainfall event. That is caused by increasing ratio between total amount rainfall and available volume inside fishponds. Factual values demonstrate the relationship between the reservoir size expressed by free available volume and particular rainfall events. The larger the free available volume of reservoir, the higher transformation effect may be expected. The results in the set of columns called *"Overall"* are related to the transformation by the entire system of water reservoirs with the final enclosure profile Starý rybník. Other columns illustrate the transformation effect of particular reservoirs without consideration of the existence of the other ones.

Although the total available volume for transformation purposes is small the transformation effect of such reservoirs is not negligible (e.g. Deml). The research shows that transformation effect is raised by proper design and functionality of the system of water reservoirs (Fig. 6).

6: *Transformation effect due to the free retention volume and rainfall event duration*

DISCUSSION

There is necessity to demand the hydrological data which include the affection by water reservoirs in order to provide the required data accuracy and reliability. There is question who would provide the entire and actual database of small water reservoirs, wetlands, drainage system admissions etc. However the problem could be solved using GIS software (Fárek *et al.*, 2014; Zlatanovic, Gavric, 2013).

Usually, we can see one prevailing function of small water reservoir, e.g. water storage, fish farm, water management, recreational, aesthetical, ecologic, sedimentation function and others. On the other hand SWR are mostly multifunctional. Reservoirs fundamentally influence water regime of the landscape, especially during dry seasons and flooding.

Outflow regulation consists of utilization of free retention volumes for water retention and discharge transformation. The results show relationship between retention volumes and transformation effect of reservoirs in dependence on the rainfall event parameters. There is assumed, that the higher the free retention volume is, the higher the transformation effect of the water reservoir or the entire system will be. Although the total available volume of three SWR for transformation purposes is rather small the transformation effect of such reservoirs is not negligible. The validation of the model is a very difficult task. The investigated system of small water reservoirs is not yet complete, Starý rybník reservoir is under construction. The problem could be solved by parallel in situ measurement of runoff on three enclosure profiles during given rainfall events with known parameters. The validation of the model represents the challenge for the future research.

CONCLUSION

The article is focused on a problem of watershed flow off transformation caused by catchment of part of the precipitation by retention volumes of small water reservoirs (SWR). The input data for design of water reservoirs are represented by water discharge data related to the water resource of particular SWR. In the Czech Republic, the data are provided by the Czech Hydrometeorological Institute (CHMI), however the data relate to the unaffected discharges, i.e. without consideration of transformation effects of existing small water reservoirs within the basin. The research was aimed at verification of assumption that system of small water reservoirs with relatively small retention volumes is able to transform the overall watershed flow off during the rainfall event. The study dealt with runoff process without detailed consideration of source of sediments in the catchment area of reservoirs.

The research involved collecting data related to the watershed, building-up transformation model for particular water reservoirs and overall model processing related to the transformation of flood discharge through the system of three small water reservoirs situated in woody-agricultural landscape (SWR Deml, Potstat, Starý rybník).

Rainfall-runoff processes were modeled in software Hydraflow Hydrographs Extension for AutoCAD Civil 3D which supports hydrological computational methods based on SCS unit hydrograph (TR-20, TR-55) and rational methods. Intensity, duration and frequency rainfall curves (IDF) were derived from the data of short-term rainfall events collected by J. Trupl.

The particular hydrographs were modeled for both subbasin and overall watershed for each rainfall event without application of the transformation effect of water reservoirs (i.e. no reservoirs exist). Consequently the hydrographs were recomputed with involvement of transformation effect of the water reservoir system. The transformation effect of particular reservoirs was computed based on retention volumes and dimensions of incident hydrotechnic structures.

The research showed that transformation effect was reached containing discussion about positive influence of system of fishponds on both water retardation and retention inside watershed and flow off rate from catchment basin. The study contributes to the consideration of transformation effect of small water reservoirs in the landscape.

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