# Extinct Ponds: Estimating Average Discharge Values for Purposes of their Water Balance Assessment in Order to Improve Management of Water Resources

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## ABSTRACT

*This paper presents the development of the methodology for estimations of runoff characteristics of small to medium catchments including all calculation procedures and methods applied for this purpose. The purpose of this analysis consists mainly in the assessment of reservoirs water balance which is one of tasks within the complex assessment of the possibility of extinct ponds restoration. For the development of the methodology for mean runoff value calculation, the multiple regression approach was adopted. Four catchment characteristics were considered as independent variables. These are catchment area, mean annual precipitation, mean annual temperature and percentage of forests which are assumed as important for mean run- off calculation. Derived equation achieved after parameterisation the value of $R^2 = 0.84$ in case of the most complex model structure. However, good results were achieved also in case of simpler model structure.*

## INTRODUCTION

Mean discharge is one of the most important characteristics when assessing the reservoir hydrologic regime for different purposes. Together with the volume of a reservoir, it is an input for calculation of a reservoir residence time. The residence time is important besides others for the process of reservoirs sedimentation. It is used for calculation of trap efficiency (TE) which is a ratio of the sediment trapped in reservoir to the total sediment flux to the reservoir (Brune, 1953; Dendy and Champion, 1978). The reservoir residence time is of course important also from the point of view of reservoir water quality in general because it directly corresponds to the time needed to exchange the water in the reservoir as discussed besides others by Ruedaa et al. (2006).

There are different approaches to the estimation of mean annual discharge in ungauged catchments having different complexity and demands on the input data. On one hand, this value can be estimated by application of different continuous hydrologic models with parameters estimated by regionalization techniques (Götzinger and Bárdossy, 2007; Kling and Gupta, 2009). On the other hand, the value of mean annual discharge can be estimated using a regression model parameterized by the analysis of the data for gauged catchments. This approach was applied for purposes of methodology for mean annual discharge estimation. This methodology is intended to provide input data for the general assessment of sediment load on water reservoirs as well as for the assessment of extinct pond areas from the point of view of their possible restoration.

## METHODOLOGY

The methodology used for given purpose was developed at the Department of Irrigation, Drainage and Landscape Engineering. It is based on nonlinear power model. Two types of such model are tested in this paper: (i) standard nonlinear power model and (ii) nonlinear power model with shifts in two directions. The general shape of the first model is given by the Equation (1), the second is described by the Equation (2). Several catchment descriptors – explanatory variables – were tested on their importance for the calculation of average discharge – dependent variable.

$$Q_a = a_0 \cdot \prod_{i=1}^{n} CD_i^{c_i} \qquad (1)$$

$$Q_a = a_0 \cdot \prod_{i=1}^{n} \left( a_i \cdot (b_i + CD_i)^{c_i} + d_i \right) + d_0 \qquad (2)$$

where $Q_a$ is mean discharge, $CD_i$ are catchment descriptors $a_i$, $b_i$, $c_i$ and $d_i$ are model parameters and n is a number of considered catchment descriptors. Shifts in case (ii) are driven by parameters $c_i$ and $d_i$.

In total, 84 catchments up to 170 km² were selected for the analyses as well as for the calculation of model parameters. For

these catchments, values of average discharges are published by Zítek et al. (1965). These values are based on measured time series from gauging stations located at the outlets. Location of considered catchments within the area of the Czech Republic is shown on Figure 1.



**Figure 1: catchments used for the analyses and for the parameterisation of the model**

Catchment descriptors considered for the calculation were catchment area (A), mean annual precipitation (P), mean annual temperature (T) and percentage of forests (F). It could be possible to involve more descriptors such as percentage of water bodies or more detailed land use characteristics but the aim was not to increase the complexity of the calculation procedure which besides others corresponds to the results published by Perrin et al. (2000). The purpose for involving first two characterisics is obvious. These determine the upper bound of average runoff. This means that the product of these two characteristics is a volume (V) which is available for the runoff. It is assumed that mean annual runoff cannot be higher than the runoff of this volume calculated as

$$Q_{a,\max} = \frac{V}{365 \cdot 24 \cdot 60 \cdot 60} \qquad (3)$$

where $Q_{a,\max}$ is the maximum value of mean discharge and V is the mean volume of precipitation in one year.

The value of $Q_{a,\max}$ cannot be exceeded under the assumption of mass conservation law in conditions of most Czech catchments. However, it is possible that the runoff is higher than the total volume of precipitation. This could be mainly the case of catchments having important subsurface water exchange with neighboring catchments which is determined mainly by the geological conditions. The example of such conditions is presented by Högström and Larsson (1968). Furthermore, there are several sources of uncertainty which can result in the higher value of runoff in comparison to available volume. This is the case of mean annual precipitation which uncertainty sources mainly from the fact that available data are interpolated from point station data and that

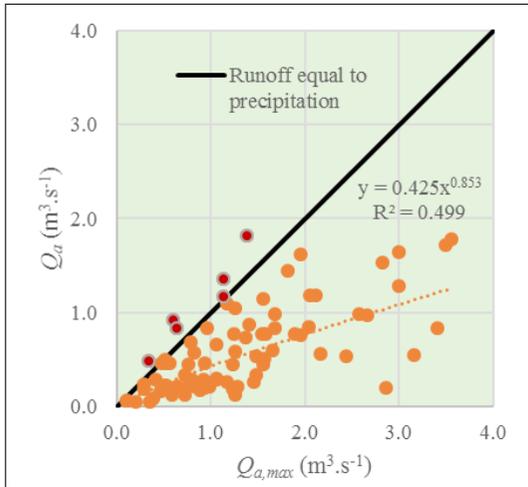they cannot reflect the spatial heterogeneity of precipitations.



**Figure 2: the relationship between maximum possible value of mean discharge and mean discharge (catchments having $Q_a > Q_{a,max}$ are marked with red colour).**

Figure 2 shows the relationship between $Q_{a,max}$ and $Q_a$ for 84 catchments in the sample. Six of them have higher mean discharge then the maximum value calculated from precipitation data. The long term transfer of water across the catchment boundary is not very usual in conditions of small catchments in the Czech Republic and therefore these catchments were excluded from the analysis.

Figure 2 also shows that the value of mean discharge ($Q_a$) decreases with its maximum possible value ($Q_{a,max}$) which corresponds to the mean volume of precipitation ($V$). $Q_{a,max}$ would explain $Q_a$ with the determination coefficient ($R^2$) value 0.499 when simple power function is used. This means that the use of simple power function and catchment descriptors A and P is insufficient.

**ANALYSES**
First analyses were focused on the assessment of influence of single catchment descriptors on the value of mean discharge. Values of every considered catchment descriptors were related to values of mean discharge and the line following power function with shifts in two directions were fitted to this relationship. The influence of each catchment descriptor on mean discharge value was then quantified using $R^2$. Further, the similar analysis was performed with consideration of specific values of mean discharge $q_a$.

**Catchment area**
Catchment area is a descriptor whose influence on $Q_a$ is obvious. The larger area results in higher value of $Q_a$.
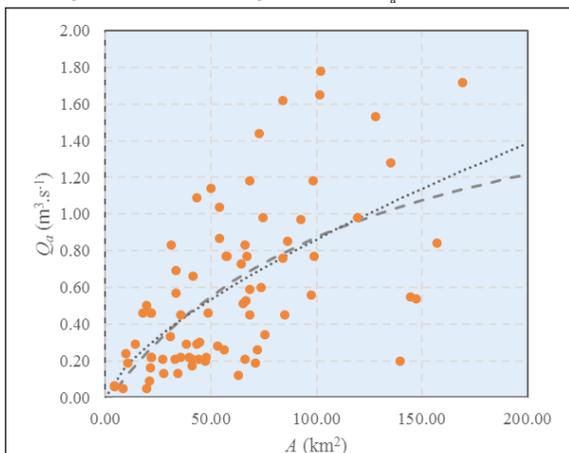


**Figure 3: the relationship between the catchment area and**

mean annual discharge (dotted line represents fitted curve according to the equation without shifts, dashed line represents fitted curve according to the equation with shifts)

Figure 3 shows that both shapes of mathematical functions give similar results up to about 120 km². The value of $R^2$ for curve with shifts and without it is 0.374 and 0.367 respectively. This value can be considered relatively high with respect to the fact that only one single catchment characteristic is assessed. This result also confirms the initial assumption on the influence of catchment area on mean annual discharge.

**Mean annual precipitation**
Mean annual precipitation over the catchment is another descriptor whose influence on $Q_a$ is obvious. The higher value of mean annual precipitation results in higher value of $Q_a$.
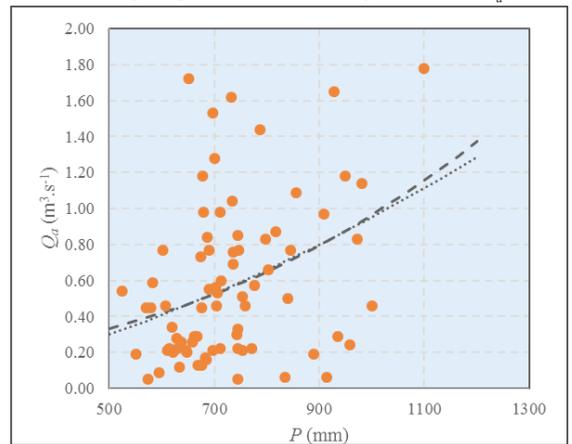


**Figure 4: the relationship between mean annual precipitation and mean annual discharge (dotted line represents fitted curve according to the equation without shifts, dashed line represents fitted curve according to the equation with shifts)**

Figure 4 shows that both shapes of fitting curves provide similar results within the whole considered range of mean annual precipitation values. Values of $R^2$ are also nearly the same being 0.129 and 0.128 respectively. These are lower than in case of the catchment area which confirms the highest importance of the catchment area for calculation of mean annual discharge. The initial assumption of positive relationship between mean annual precipitation and discharge is confirmed by the results also in this case.

**Mean annual temperature**
Mean annual temperature in the catchment is another descriptor which was considered having important influence on $Q_a$. It was assumed that higher value of mean temperature results in lower values of $Q_a$ through its influence on evapotranspiration which is generally expected to be higher in case of higher temperature.
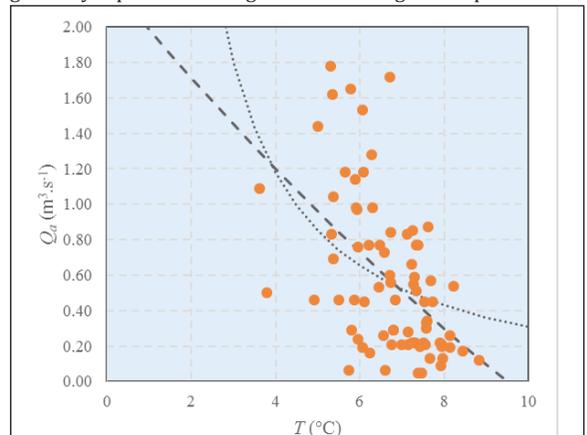


**Figure 5: the relationship between mean annual tempera-**

ture and mean annual discharge (dotted line represents fitted curve according to the equation without shifts, dashed line represents fitted curve according to the equation with shifts)

The results shown in Figure 5 confirm the assumption of decreasing value of $Q_a$ with increasing mean temperature. The values of $R^2$ which are for curve with shifts and without it 0.266 for and 0.189 respectively are again relatively low but higher than in case of mean annual precipitation. Another outcome is that in this case, the model structure considering shifts can provide better results.

### Percentage of forested land
This catchment characteristic is assumed to affect mean discharge through its influence on evapotranspiration. Thus, higher percentage of forests should lead to lower values of $Q_a$ because there is less water to be run off.
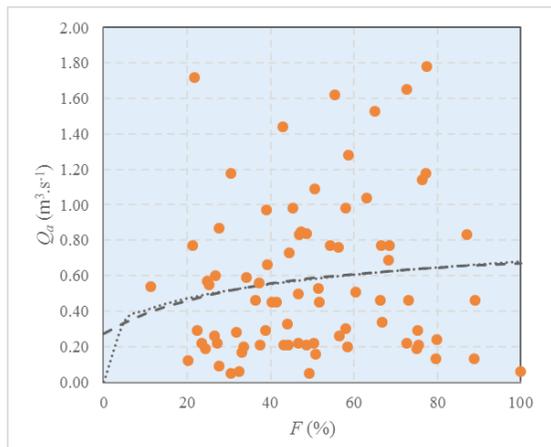


**Figure 6: the relationship between percentage of forested land and mean annual discharge (dotted line represents fitted curve according to the equation without shifts, dashed line represents fitted curve according to the equation with shifts)**

Figure 6 shows that both shapes of fitting curves provide similar results within almost the whole possible range of forest percentage except of very low percentages for which the shape is broken at the value about 5 %. Thus, the application of shifts is considered reasonable. However, the values of R2 are very low in both cases being for curve with shifts and without it 0.018 and 0.016 respectively. This could be interpreted in that way that this parameter cannot improve the performance of the methodology. However, percentage of forested land was not excluded from the parameterisation because its influence can be suppressed by the stronger influence of other catchment characteristics.

## RESULTS
Parameterisation of the methodology was carried out by automated minimisation of $R^2$ value using gradient method available in MS Excel as it is not possible to linearize the problem by logarithmic transformation due to the shifts. The model achieved the value or $R^2 = 0.805$ in case of simpler model structure - Equation (1) and $R^2 = 0.840$ in case of consideration of shifts - Equation (2). Optimised parameters for the model structure having best performance are shown in Table 1. In case of this model structure, the value of root mean square error (RMSE) is 0.18 $m^3 \cdot s^{-1}$ and its relative value is 30.8 %.

**TABLE – 1**
**OPTIMISED PARAMETERS**

|  | a | b | c | d |
|---|---|---|---|---|
| global (index 0) | $4.28 \cdot 10^{-6}$ | - | - | 0.043 |
| A (index 1) | 1* | 8.450 | 0.646 | -4.845 |
| P (index 2) | 1* | 469.8 | 1.122 | 396.6 |
| T (index 3) | 1* | 4.398 | -0.299 | -0.458 |
| F (index 4) | 1* | 0.175 | -0.388 | 133.6 |

**\*parameters $a_i$ were recalculated in order to be 1 which was done by dividing each single function by optimised value of $a_i$ and multiplying $a_0$ by this value.**

## CONCLUSIONS
Presented results show that proposed methodology provides sufficient results. The value of $R^2 = 0.84$ denotes good relationship and relative value of RMSE is close to the value given by Czech standard (Kulasová and Holík, 1997) for hydrologic data which are supposed to be used for design purposes which is 30 % for catchments of fourth category. These are catchments with no measured data for which hydrologic characteristics are derived mostly using hydrologic similarity approach. Better results were achieved in case of application of more complex model structure considering shifts of power function curves. However, the performance of the model is not much lower in case of the application of simpler model structure. This means that also simpler model structure can be applied which is considered to be more robust having less parameters.

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