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TIDAL EFFECTS ON SMALL CATCHMENTS

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Abstract

The content of this article is the analysis of the tidal effects on the flow which is measured on a long-term basis. Influence of the Moon gravity leads to a movement of fluid in the upper layer of the Earth's cover. As a result, a greater amount of water is expelled into the water flow periodically with a period of 12 hours. In this paper we deal with the analysis of this contribution. Size of the tidal contribution is changing with the time depending on the distance and position of the Moon and the Sun. We present the results of the analysis from few weeks data obtained during rainless period. The mean values of the tidal effects on the flow measured by us make 0,074 ± 0,069 l/s for Teply Brook and 0,012 ± 0,008 l/s for Starosuchdolsky Brook.

Key words: tides, Fourier analysis, water discharge, stream.

INTRODUCTION

While in the coastal areas the observation of the tide is relatively easy and applies to life of practically all the people in this area, in the conditions of the Czech Republic it is necessary to do the observation by using measuring techniques.

Usually, the observation of tidal effects is carried out in the undrawn wells. While the movement of free oceans fluid is causing a tidal wave with amplitude of normally a few meters, fluid flowing through the porous rock causes oscillation of just about several centimetres in the wells.

For example, the well KV1 oscillates at an amplitude of about 12.5 cm. However, from the wells observed so far, it is the highest value. It is interesting that the change of the gravitational acceleration is able to cause oscillation in some wells in the antiphase against the assumed monthly flow.

This effect is explained by the declination of the relatively freely stored plate in the vicinity of the well. Wells with antiphase are found, however, only very rarely (e.g. KV18). In most cases the classic tidal wave is observed. For this reason, the overall contribution of the tidal effects on the levels of surface flows is positive.

And so if the Moon is in the zenith and also 12 hours after, the amount of water flowing from the spring is higher. The tidal analysis of several streams is followed for example by RENSEL, FORSTER (2003). In addition to the Moon in some cases also the effect of the Sun position at the flow rate of the stream is evident. However, it is approximately 12 times weaker.

The biggest change of the gravitational acceleration and therefore, even the strongest tidal effects occurre always during the eclipse of the Moon or the Sun, because the effect of both elements adds together. The calculation is elegantly executed in the work by MOŠNA (2014). If, therefore, we monitor with a sufficiently fine resolution the flow rate of the unregulated water flow, there is a fair chance to detect the contributions of the tide.

We have chosen for the analysis of these effects two of the four catchments measured by our group, namely Teply Brook catchment and Starosuchdolsky Brook catchment.

MATERIALS AND METHODS

The **Teply Brook catchment** is located about 25 km south from the town of Žďár nad Sázavou, Czech Republic. The catchment characteristics were derived from a detailed GIS analysis, and they are summarised in Tab. 1. The elevation ranges from 417 m to 602 m, with a mean elevation slightly over 500 m. The mean catchment slope is about 22 %, with maximum slopes more than 55 % occurring in the middle part of the catchment. The geology of the catchment is composed mainly of metamorphic rocks (gneiss, amphibolite, migmatite). In the lower elevations of the catchment area it is composed mainly of peridotite and serpentinite. Alluvial deposits of loamy sands and gravels occur at the valley bottom.

As far as the soil composition is concerned, forms of cambisols and ceptosols are typical for the catchment area, and are present as haplic cambisols, alcalic or cambic leptosols. In the valley of the stream we find fluvic cambisols and gleysols (FAO-WRB 2006).

The prevailing land use is a mixed semi-natural forest of spruce *(Picea abies)*, pine *(Pinus sylvestris)*, hornbeam *(Carpinus betulus)* and alder *(Alnus incana)*. Arable land is found only in the southern part of the catchment area. The climate is moderately warm and humid, with estimated mean annual precipitation of 650 – 750 mm, and mean annual temperature of 7 °C.

Tab. 1. – Characteristics of the Teply Brook catchment

A	Catchment area	1.56	km^2
L_{th}	Length of thalweg	1.41	km
L_{MF}	Length of main river	1.10	km
P	Length of water divide	5.13	km
B	Average width of catchment	1.10	km
I_R	Average slope of river	13.0	%
I_S	Average catchment slope	15.1	%
$H_{max.}$	Maximum catchment elevation	595	m a.s.l.
$H_{min.}$	Minimum catchment elevation (outlet)	417	m a.s.l.

The **Starosuchdolský Brook catchment** is located at the north side of Suchdol village, which is now part of the Prague Metropolitan area. The Starosuchdolsky brook rises at an elevation of 230 m The length of the stream (to the outlet) is 580 m, and the catchment area is 2.95 km^2. The brook forms a right side tributary to the Uneticky brook, which flows into the Vltava River. The catchment area characteristics have been derived from a detailed GIS analysis, and they are summarised in Tab. 2.

The morphology of the catchment area is mostly flat, with a slope of up to approximately 5 %. However, the slopes in the forested part of the catchment area are up to 36 %. The shape of the catchment area is elongated; in the South West part of the catchment, the highest point is at an elevation of 335 m and the outlet is located at an elevation of 211 m.

Geomorphologically, the site of the catchment area falls within the district of the Tursko plateau, which is formed mainly from upper proterozoic and cenomanian conglomerates, sandstones, clay stones and sponge-spicule rock (spiculites). The bedrock of the forested slopes near the Starosuchdolsky brook is formed by proterozoic siltstones and graywackes, which rise up on the surface in places with a higher slope. However, most of the base is formed by loess, loamy sands and debris, as a result of geological processes during the quaternary period.

Tab. 2. – Characteristics of the Starosuchdolsky Brook catchment

Catchment area/ basin	km^2	A	2.946
Maximum catchment elevation	m a.s.l.	H_{max}	335
Minimum catchment elevation (outlet)	m a.s.l.	H_{min}	211
Elevation of brook source	m a.s.l.	H_{pr}	230
Length of thalweg	km	L_{th}	3.7
Length of brook	km	L_b	0.58
Length of catchment divide	km	P	9.1
Average slope of brook	%	i_b	5.4
Shape of catchment	-	A	0.2

As the soils types are mostly haplic fluvisols, gleysols and cambisols, the prevailing land use is arable land (53 %) and urbanised areas (36 %). The forest area is a mix of semi-naturals. Besides arable land and an urbanized area, with a relatively high population density, the downstream part of the catchment is environmentally protected in its riparian belts by a valuable canopy. These river belts, situated on both sides, contain typical local forest species, represented by alder (*Alnus glutinosa*), ash (*Fraxinus excelsior*), oak (*Quercus robur*), and sporadically hornbeam (*Carpinus betulus*). The climate is moderately warm and semiarid, with an estimated mean annual precipitation of 350 – 400 mm, with a mean annual temperature of 8.8 °C.

The water column was measured at 1.0 m upstream by the Vegawell 71 submersible level gauge and the V-notched weir (Figs. 1a, 1b) with a sapphire membrane, having a range of application from 0.0 m to 1.0 m. The water levels were measured on both experimental catchment profiles. The Drak3 AD converter was used for digitization. The data was stored in a standard PC, installed in the Technical Maintenance building of the alternative storage for fuel from the Skalka Nuclear Power Plant (Teply Brook) and Spaleny Mlyn residence (Starosuchdolsky Brook), reported by ZEMAN (2007).

The discharges of the two catchment areas were determined from the water levels on the Thomson spillway, which was located at their outlets (Figs. 1a and 1b).

Fig. 1a – Hydrometric profile on the Teply Brook

Fig. 1b – Hydrometric profile on the Starosuchdolsky Brook

In the time series of the discharge data, a component with 12 hour period was found. This was realized by fitting data by function (1).

$$Q(t) = \sum_{i=1}^{3} V_i e^{-\frac{t}{\tau_i}} + \sum_{i=1}^{2} A_i \sin \frac{2i\pi t + \varphi_i}{86400} \qquad (1)$$

where

V_i … tributaries of individual soil zones (l/s)
τ_i … relaxation times of the depletion of soil zones (s)
A_i … the elements of the periodic expansion (l/s)
$Q(t)$ … discharge depending on the time (l/s)
t … time (s)
φ_i … phases of the day (s)

Eq. (1) corresponds to the zone depletion in DVOŘÁKOVÁ, ZEMAN (2014) and to the influence of evapotranspiration in the coefficient A_1, which represents the first member of the harmonic expansion. The second member of the harmonic expansion includes tidal and therefore double frequency. The intensity of this effect is given by the coefficient A_2.

To this component, for each day separately, also phase φ_2 of this signal and the moment of the maxima have been found. Sunrises and sunsets and moonrises and moonsets were found in the astronomical yearbooks. The moments of the maxima were correlated with the predicted maxima of the tide occurrence, therefore, with the moments when the Moon is in the zenith. From the difference of these times of maxima a delay has been found caused by the time of flow of expelled water through the porous rock and the time of flow of this already free surface water through the basin to the place of the closing profile.

RESULTS

The Fig. 2 shows an example of a well visible tides on Starosuchdolsky Brook on 26th July 2013. In the figure, the measured data and the best fitting by function (1) are shown.

Fig. 3 shows the phase φ_2 (eq. 1) on the moments of the tidal maxima. The coefficient of determination of these moments is $R_1^2 = 0{,}4755$ for Teply Brook.

Fig. 4 shows the phase φ_2 (eq. 1) on the moments of the tidal maxims. The correlation coefficient of these moments is $R_2^2 = 0{,}4261$ for Starosuchdolsky Brook.

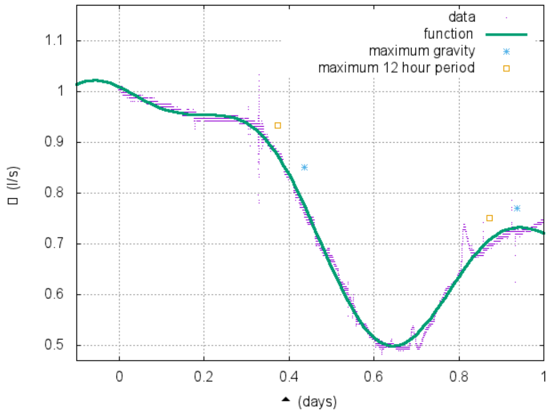

Fig. 2. – Example of tides on Starosuchdolsky Brook

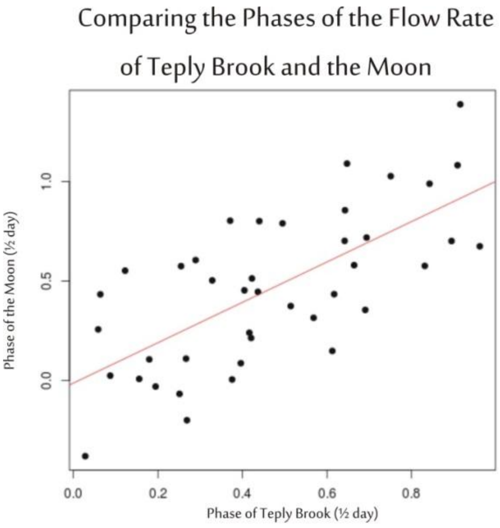

Fig. 3. – Dependence of discharge maxima of Teply Brook on the moments of gravitational acceleration maxima

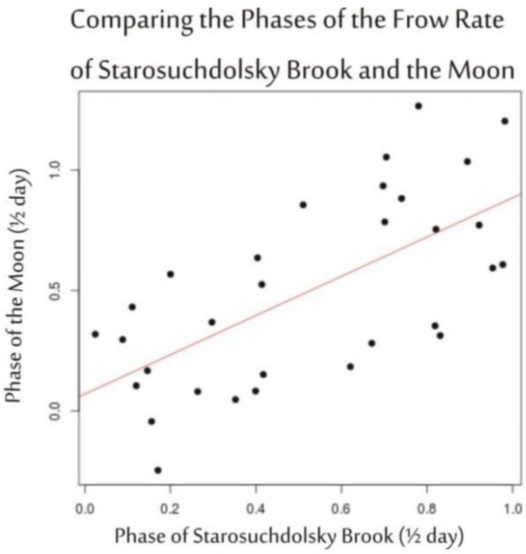

Fig. 4. – Dependence of discharge maxima of Starosuchdolsky Brook on the moments of gravitational acceleration maxima

Tab. 3. shows the comparison of the mean values of the moments of the maxima of the second members of the harmonic expansions according to the eq. (1) with the predicted maximum tidal effects according to the immediate astronomical constellation of the individual catchments, where $s_{\varphi 2}$ are standard deviations of mean values of time delay.

Tab. 3. – Mean values of discharge delay after gravitational acceleration maximum

	Teply Brook	Starosuchdolsky Brook
$\bar{\varphi}_2(s)$	4200	600
$s_{\varphi_2}(s)$	13000	14000

DISCUSSION

As we found out on the example of the two small catchments the tidal effect is still noticeable and demonstrable. The coefficient of determination R^2 is proving this. Generally, the more tributaries there are in the catchments, the possibility of detection of tidal effects in the resulting flow detect is worse. This is due to the fact that in the flow of the various tributaries tidal effects occure with different phases and the mutual uncoherency of these tributaries makes the detection of tidal effect less easy in summation of flow rates in the resulting bigger flow.

Tab. 3 shows that average delay of the maximum discharge after gravitational maximum is practically zero for Starosuchdolsky brook and therefore the increase of the gravitational acceleration causes a pressing out of water from the subsoil. In the case of Teply Brook the delay of the maximum discharge after gravitational maximum is negative, and thus pores in the Earth's layer are opening by the influence of gravity, they acquire water and this results the loss of the water flowing through the river basin.

The phase delay is given in accordance with GEORGAS (2001) from 17,5° to 355,1°for Stony Brook Harbor, Long Island, New York, which calculated to a time corresponding to a delay from 36 minutes 14 seconds to 12 hours 15 minutes 5 seconds. Our results are similar for both brooks, i.e., for Teply brook 1 hour 10 minutes and for Starosuchdolsky brook 10 minutes. However, it is important that the tidal influence on both of us measured brooks was approved, because the tidal signal is often immeasurable for many basins due to infiltration and the addition of tributaries.

A better correlation result could be reached when using the actual period of the tide, i.e. 12 hours, 25 minutes and 14 seconds. We, however, tried for the development of the series as the second harmonic frequency to 24 hourly cycle of evapotranspiration.

CONCLUSIONS

We managed to detect the influence of the tides on the flow rate through the basin by harmonic analysis of the flow on the two small catchments (1,5 km^2 and 3 km^2) by adding a second member. The coefficients of determination R_1^2 and R_2^2 showed that there really are tidal effects. These coefficients show a strong dependence between the moments of the phase maxima of the gravitational acceleration and the flow rate. The value of secondary delay between the maxima of these signals gives evidence about the mechanics of the bedrock of the catchments.

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