ANALYSIS OF FLUCTUATIONS IN THE STREAM WATER LEVEL DURING THE DRY SEASON IN FORESTED AREAS

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This is a description of temporal variation and development of stream flow in the open landscape, in the long-term summer droughts. The water level was scanned continuously several times a minute for several consecutive years. The analysis shows that the water discharge in the stream can be clearly divided into two components, a tributary to surface water and groundwater. While the surface component has a clear daily period, a component of groundwater is declining continuously, almost linearly. In the stream surface component adds to the total water discharge a gradual effect mini-peak levels at sunset and a sharp decline at sunrise. Time of culmination and its overall size with the ongoing drought days is developing. The peak always comes later and is still less pronounced.

drought; fluctuation levels; evaporation; forest respiration; dynamics of fluctuations; Thomson V Notched weir; discharge

INTRODUCTION

Behavior of water flows in extreme situations and the dynamic changes in the flow are governed by a number of contemporary works (Kovář et al., 2006), both important for predicting levels during floods, and the behavior of flows in the drying, is today, when in the coming decades are expected significant climate changes, extremely important issue (Frederick, Major, 1997). This paper seeks to contribute to describing the dynamics of fluctuations in small flow streams. It deals with the analysis of drought monitoring on Teplý potok (Warm Brook) in 2003–2007 (Zeman, 2007). We show acquired flow data together with the behavior of accompanying variables during these periods such as temperature and relative humidity. We present also general explanation of shown fluctuations. We believe that a detailed analysis of the daily flow can be a source of valuable information about the catchment and the parameters of capacity and throughput of hydrological structures and flow relationships among them. Model idea of catchment area description generally corresponds with the models used in work (Mul et al., 2007), based on the fundamental work about the diurnal fluctuation (Burt, 1979). There are therefore works that try to represent the best the real behavior of flows in the Czech Republic (Dvořáková, 2005).

MATERIAL AND METHODS

Description of watershed and measurement technology

Measurement was in progress for four years in the period 2003–2007 in South Moravia, where in the valley Nedvědičky the watershed of Teplý potok is situated (Fig. 1). Average discharge of Teplý potok in the summer months is around 1.8 l/s. During the spring melting this is about 800 l/s. The watershed of Teplý potok consists of 1.9 km^2 mostly pine forest (the rest of hornbeam and alder) and 0.4 km^2 meadows. In the first third of the flow prevails slope about 7°, in the remaining flow about 12°. The stream bottom is stony, streamsides of a small part (about 10%) grassy; the rest is transfer to the forest. In the basin there are no hydraulic structures. Streambed is uniform in

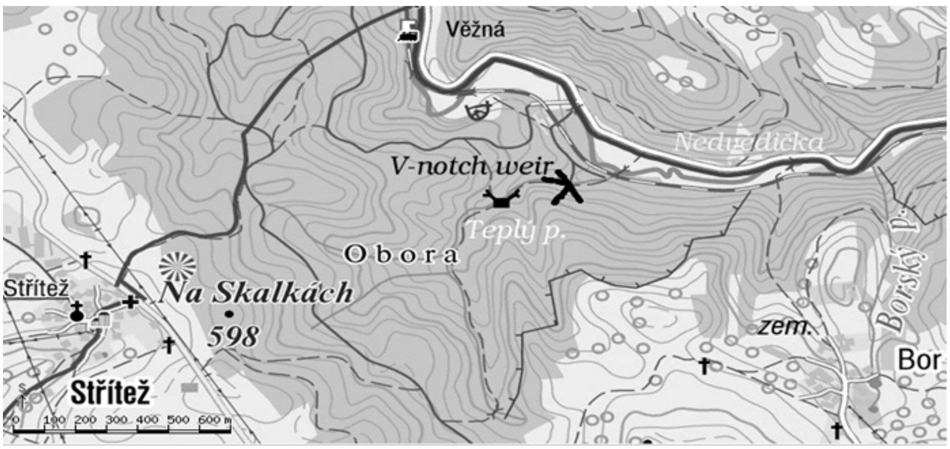

Fig. 1. General map of the basin Teplý potok

length of 700 m, further divides to three shoulders – length 460 m, 690 m and 635 m forming angles 30° and 90°.

The lower part of the stream and one arm is at a distance of 20 m from the stream surrounded by forest asphalt road of width 3 m. The stream lines the road to 1320 m. The actual measurement of stream flow takes place only 70 meters from its entry to Nedvědičky. Here is the stream below the asphalt road already mentioned given to two pipes with a diameter of 120 cm. At the end of the pipes spillway V-shape (Thomson V Notched weir) is located (Fig. 2).

During the season without rain due to unequal height location of pipes water is leaking from only one of them. By submersible level gauge Vega Vegawell 71 with a range of 0–1 m water column with a saphire membrane was measured at 1 m in front of the V-Notched weir water level height. For the digitization AD converter Drak3 from company Papouch s.r.o. was used. Data were stored in the classic PC installed in the building of the Technical Maintenance of Explorational Stoles of alternative storage of burned-up nuclear fuel from our nuclear power plants – Skalka. Measurements were made in the period of 1.56 s. The theoretical distinction of water level was 0.1 mm, what corresponds to the flow 6 cm^3/s (0.4%). For the analysis we selected series of cloudless days in the summer months in the following periods:

- 14.–21. 7. 2003
- 26.–29. 7. 2003
- **1.–9. 8. 2003**
- **13.6.–12. 7. 2004**
- **16.–22. 7. 2004**
- **8.–14. 8. 2005**

Measured values

The following graphs (Figs 3, 4, 5) show discharges of Teplý potok in terms of selected droughts. For clarity and especially illustration every dry period is divided into 24-hour blocks, the graph begins at midnight UTC and ends at midnight as well as the following. Individual curves in the graphs represent the flow behavior during those 24 hours, daily fluctuation is about 40% of the total flow of the stream. Discharge was determined from water level measured 1 m upstream from the weir and calculated according to equation (1).

$$Q = \frac{8}{15}(0.565 + 0.0868 \cdot h^{-0.05}) \cdot h^2 \cdot \sqrt{2gh} \qquad (1)$$

Where: Q – discharge (m^3/s)
h – water level (m)
g – gravitational acceleration 9.81 m/s^2

As can be reasonably assumed that the evaporation and respiration of the forest is both a function of light intensity, respectively and also a function of temperature and relative humidity moments of sunrise and sunset are shown in Figs 3 and 5 and in Figs 9, 10,11 daily temperatures in the monitored days are presented. Humidity during the night is almost 100% (as shown by the continuous measurement in 2004–2005), and so in Table 2 only the average

Fig. 2. Specific profile of Teplý potok

humidity in periods from 8:00 a.m. to 4:00 p.m. hours each day under consideration in 2004 and 2005 is listed.

Analysis of measured values

If we draw the stream water level as a series of values throughout the drought, we can see that it is possible (Fig. 7) to distinguish a linear trend-level fall. Overall downward trends in water levels are in Table 1. In Table 2 there are trends obtained by linear approximation as a decrease from 3:00 p.m. to 9:00 p.m. hours of each day of drought.

Because at night the relative humidity in a given period is about 100%, we assume that no evaporation and surface component of the flow contribution are continuously supported by groundwater. In order to quantify the evaporation each day, Table 2 contains a mean temperature and relative humidity between 8:00 a.m. and 4 p.m. hours, when the temperatures do not vary much as shown in Figs 9–11. Medium humidity in 2003 is not listed in the table because it was not measured. The table also indicates the total discharge Q in Teplý potok stream-bed each day and the estimated size of the contribution of surface water counted as the difference between the total daily discharge Q and the linear trend of groundwater specified by parameters a and b. These parameters are determined from the flow tendency in the afternoon, when there is no contribution of surface waters. Afternoon flow is approximated by the equation

$$Q = at + b \qquad (2)$$

Where: Q – hourly discharge (m^3/h)
a – hourly change of discharge (l/h)
b – estimated initial discharge at the beginning of the day (m^3/h)

Table 1. Overview of the overall declining trends in the levels of dry periods. Linear approximation by function f (t) = $At + B$

Drought	A (l/h^2)	B (m^3/h)
1.–9. 8. 2003	–2.86	2.4
8.–14. 8. 2005	–7.29	8.15
16.–22. 7. 2004	–7.43	5.53

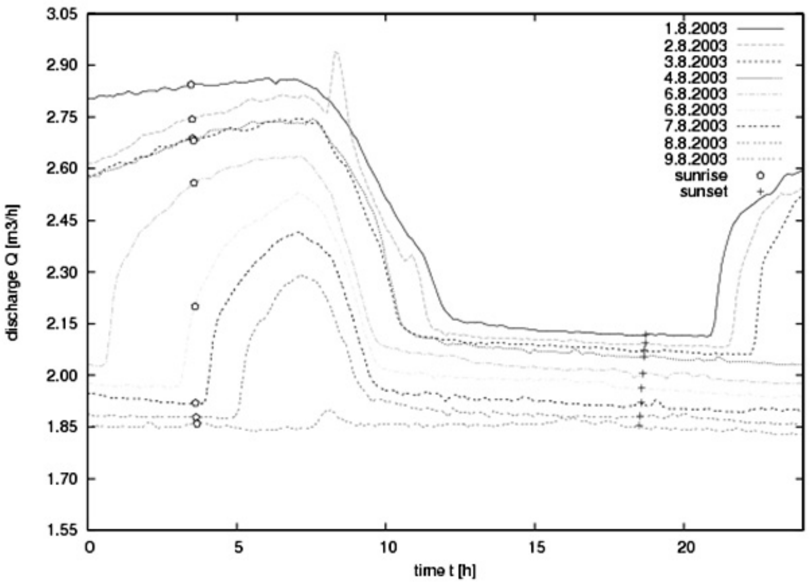

Fig. 3. Hydrograph of Teplý potok flow in the period 1.–9. 8. 2003 with marked moments of sunrise and sunset

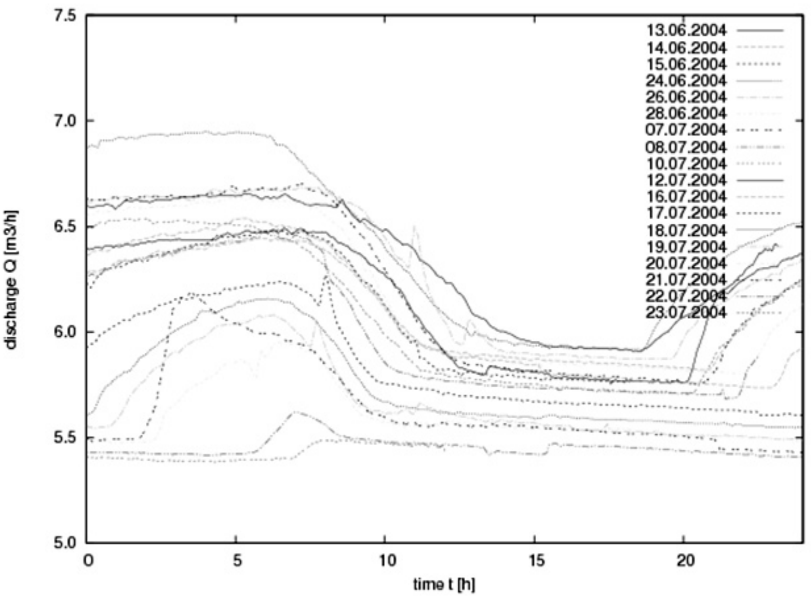

Fig. 4. Hydrograph of Teplý potok flow in the period 13. 6.–23. 7. 2004

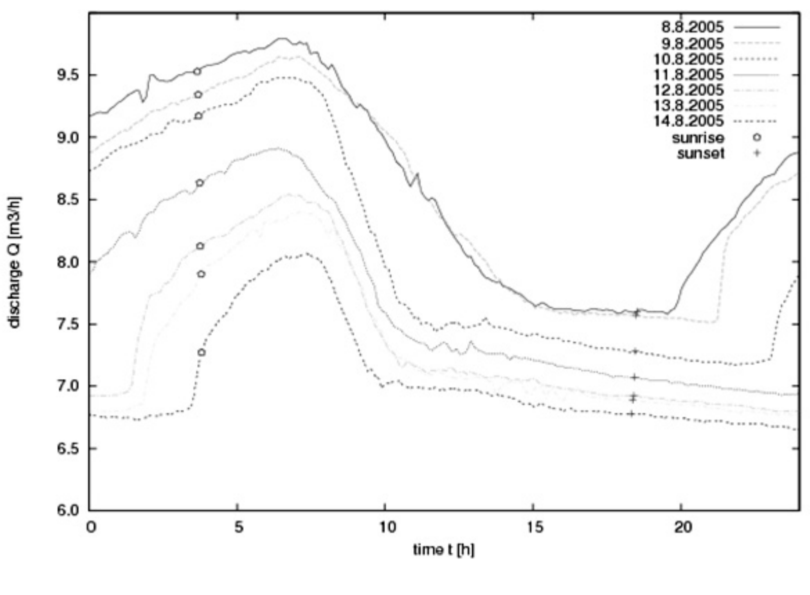

Fig. 5. Hydrograph of Teplý potok flow in the period 8.–14. 8. 2005 with marked moments of sunrise and sunset

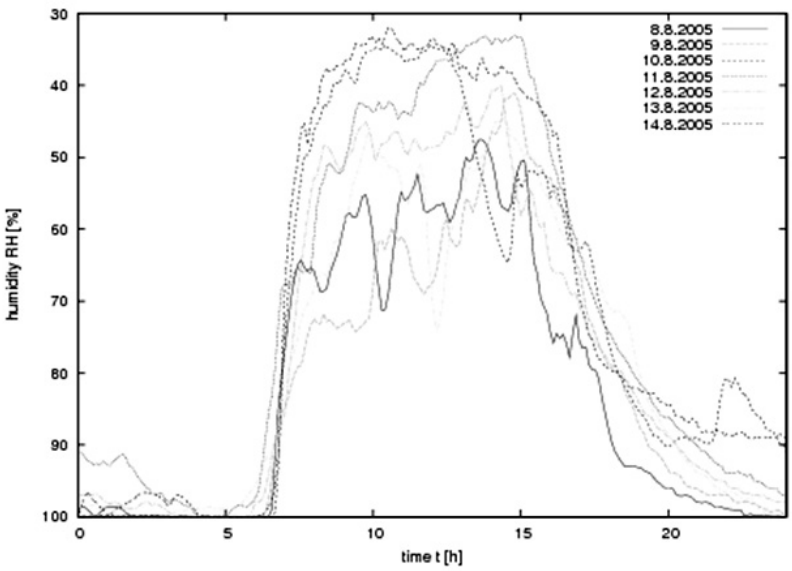

Fig. 6. 24-hour course of humidity. A typical course of humidity 2 m above the surface in dry clear days shows that after the first seven hours the humidity jumps from 100% to almost constant value. After 4 p.m. it quickly rises back to 100%

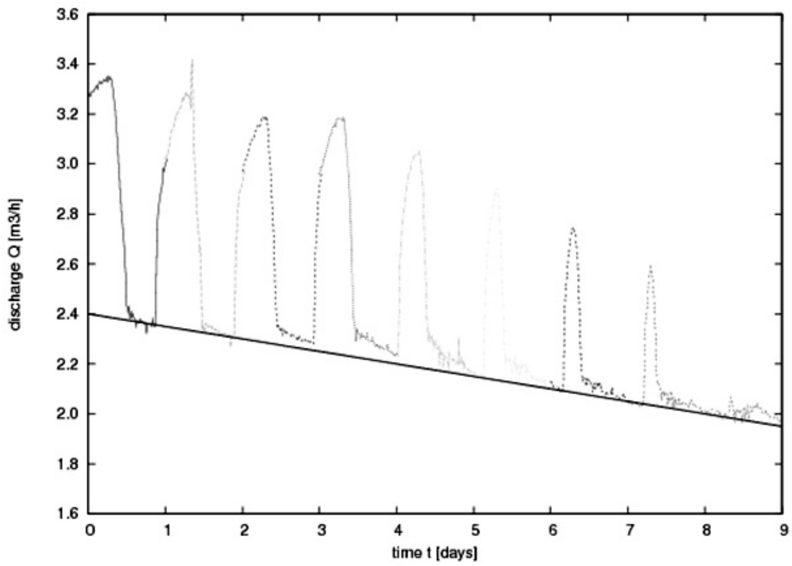

Fig. 7. Progression of water level in Teplý potok throughout the dry season 1.–9. 8. 2003, indicating an overall trend of decreasing levels

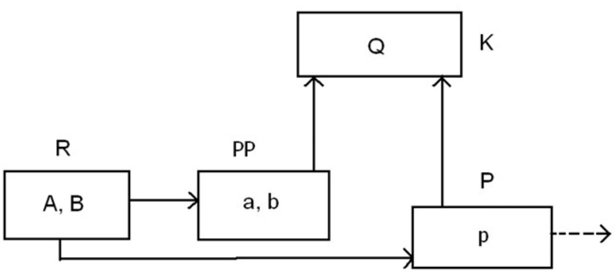

Fig. 8. Water flow scheme

Legend to Fig. 8: Reservoir *R* is continuously supplying the subsurface layer *PP* and surface layer *P*. The surface layer *P* is drained by direct runoff to stream-bed *K* at first and by evaporation the second. Subsurface layer *PP* removes only the water drained into the stream-bed K. Status and change of the reservoir *R* are described by the parameters *A*, *B* from Table 1. Status and change in subsurface layers are described by the parameters *a*, *b* from Table 2. The total quantity of water supplied by the surface layer for each day is estimated by parameter *p* in Table 2. The total quantity of water that flows through the stream-bed during particular day is specified by parameter *Q* in Table 2.

Unlike the coefficients *a* and *b*, which show almost linear decline in available water to the flow from other sources than the surface, Table 1 contains the coefficients *A*, *B*, obtained as a long-term downward trend in water level over the entire period of drought, what is illustrated by a straight line in Fig. 7, which corresponds to the decrease in the total amount of water in the basin. Coefficients *a*, *b* thus show saturation of subsurface layer, which has a direct runoff through the discharge profile. Coefficients *A*, *B* show the overall decline in water together in all layers of the river basin, namely in the total saturation of the reservoir.

DISCUSSION

This study has been aimed at the simplest model hydrosystem of Teplý potok. It would be practical that this model is linear. This model must allow describing all basic measured features of the behavior of Teplý potok during the drought. We will freely follow the model describing

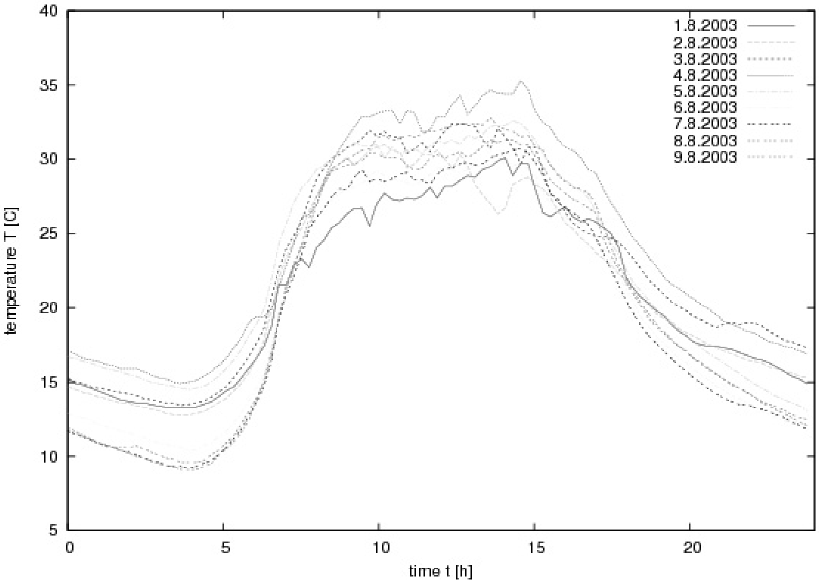

Fig. 9. Temperatures progression each day of drought 1.–9. 8. 2003. The temperature was measured 2 m above grassy surface 92 m from the point of flow measuring with time step 4.022 sec

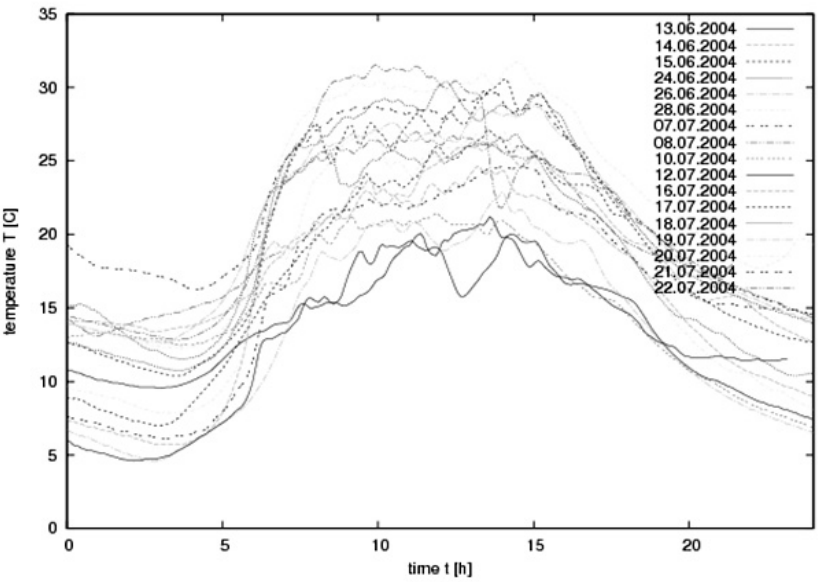

Fig. 10. Temperatures progression in each day of drought 13. 6.–22. 7. 2004

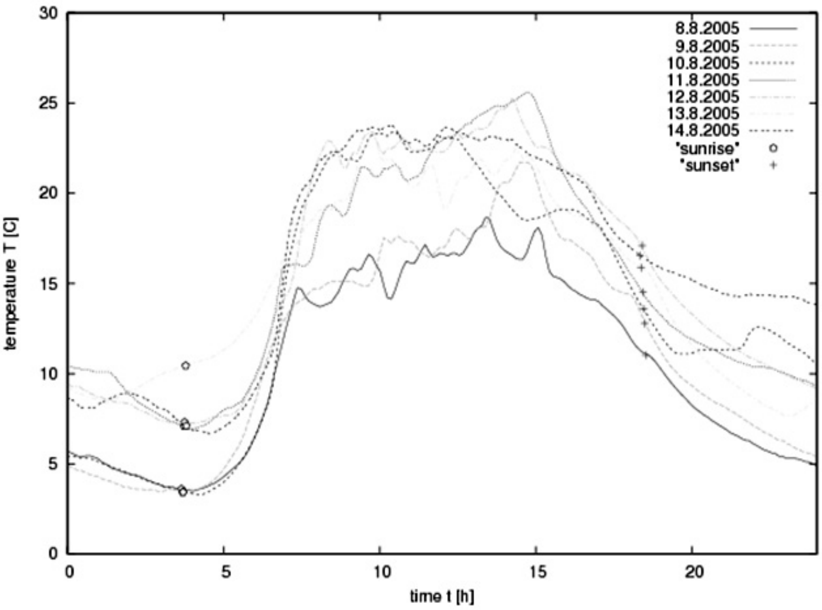

Fig. 11. Temperatures progression each day of drought 8.–14. 8. 2005

Table 2. Trends in water levels each day during the dry season between 3 and 9 o'clock p.m.

	a (l/h²)	*b* (m³/h)	*TP* (°C)	*RH* (%)	*Q* (m³/day)	*p* (m³)	*D* (m³)
2003							
01. 08.	–7.69	2.40	27.59	x	79.37	24.07	x
02. 08.	–8.57	2.34	29.07	x	75.11	21.48	2.59
03. 08.	–9.32	2.30	30.79	x	71.10	18.52	2.97
04. 08.	–10.97	2.27	32.78	x	68.77	17.48	1.03
05. 08.	–9.86	2.17	30.92	x	61.82	10.89	6.59
06. 08.	–15.21	2.10	28.60	x	55.17	9.18	1.71
07. 08.	–9.03	1.97	28.91	x	51.27	6.63	2.55
08. 08.	–1.17	1.88	31.12	x	47.68	2.92	3.71
09. 08.	–8.05	1.85	29.96	x	43.78	1.66	1.26
avg.	–8.87	2.14	29.97				
2004							
13. 06.	–81.14	5.93	18.38	53.04	181.38	62.32	x
14. 06.	–23.36	5.75	22.79	38.94	163.91	32.62	29.70
15. 06.	–22.27	5.49	24.33	45.77	123.49	x [1)]	x
24. 06.	–18.69	6.01	25.16	34.62	192.18	53.23	x
26. 06.	–12.69	5.85	20.18	44.87	178.99	42.35	x
28. 06.	–30.88	5.73	25.42	37.98	167.43	38.82	x
07. 07.	–27.89	5.54	22.81	38.76	171.12	46.09	x
08. 07.	–17.23	5.31	25.88	54.77	143.18	20.69	25.39
10. 07.	–13.23	5.32	20.30	42.58	159.42	35.49	x
12. 07.	–13.39	5.48	17.90	56.59	159.75	32.15	x
16. 07.	–36.20	5.53	23.91	57.60	156.41	34.19	x
17. 07.	–29.45	5.08	27.80	41.38	138.58	25.07	9.12
18. 07.	–10.00	4.87	28.55	48.52	130.21	16.31	8.75
19. 07.	–29.67	4.72	27.25	46.28	124.81	20.05	–3.73
20. 07.	–21.07	4.67	30.08	41.27	118.96	11.42	8.63
21. 07.	–16.12	4.67	28.48	41.73	122.70	15.16	–3.74
22. 07.	–24.22	4.48	28.50	47.78	107.41	6.81	8.35
avg.	–23.82	4.86	27.79	46.37			
2005							
08. 08.	–7.87	8.15	16.21	58.40	233.44	40.04	x
09. 08.	–16.52	8.12	17.61	60.51	229.38	39.24	0.80
10. 08.	–47.00	7.80	21.38	43.54	213.33	39.66	–0.43
11. 08.	–43.21	7.52	22.35	40.84	199.50	31.48	8.18
12. 08.	–30.66	7.29	22.89	48.74	188.54	22.42	9.06
13. 08.	–35.74	7.26	20.91	54.61	185.47	21.57	0.85
14. 08.	–21.59	7.08	22.81	36.94	177.63	13.89	7.68
avg.	–28.94	7.6	20.59	49.08			

a – hourly change of discharge (l/h²), see formula (2)
b – hourly discharge (m³/h), see formula (2)
TP – main air temperature at 8:00 a.m. to 4:00 p.m. (°C)
RH – main humidity at 8:00 a.m. to 4:00 p.m. (%)
Q – total daily discharge (m³/day)
p – volume of added increases of water level (m³)
D – difference of increases water level volume (m³)
[1)] power outage caused the suspension measurements for approximately 2 hours

the mountain streams in the Tanzanian Mountains (M u l et. al., 2007).

Altogether, data from Table 2 can be explained for instance in this way. Groundwater by capillary action waters close subsurface layer (hypodermal runoff), which is directly affected by respiratory activity and surface evaporation, so the layer, that is already deeper than the roots of breathing plants and trees, but even with the surface water makes a contribution to the overall condition of instantaneous flow discharge. In the period of the day surface layer during the dry season is quickly draining, because it is being cancelled not only by watercourse, but also by evaporation and plant respiration. Subsurface layer is drained by contrast almost exclusively by the watercourse. During the night, due to the low evaporation the surface and subsurface layers are quickly watered. Source of flooding these classes is how we think probably groundwater. It is because the effect of vapor condensation from the air (formation of dew) does not reveal any flow in charts, for its increase does not appear there after twilight even daybreak when dew formation is the most prominent. In Table 1 the coefficients *a*, *b* show status and changes in the subsurface reservoir, which supplies both near surface layers. This hypothesis also suggests an almost constant ratio between the directives of particular days and the main directive of the trend of whole dry period. This ratio is about 3.2. Our basic idea about the possible model describes the diagram in Fig. 8. Unfortunately, we could not find a working relationship between the subsidy to surface water, which is listed in the table in column *D* and the temperature and humidity.

Difference of parameters of linear regression in Table 2 can be explained by both the different baseline levels and also different drying temperatures in the basin. Figs 3, 4, 5 show the evolution of these different histories after subtraction of long-lasting trend. Fig. 11 demonstrates that this period is an initial period of temperature change, and this is with certain retardation beginning of discharge descending in the stream.

Most probably there is a process of transpiration of the forest and meadows, as direct evaporation from the almost completely covered stream will not be significantly affected by the time of day. Model describing the return of this component of elevation water levels in the stream has not been yet available, but it is clear that it is directly influenced by water levels in this deposit. For this reason, we believe that it is a water source in a thin layer under surface, whose power extends to a depth of roots of forest cover. The vegetation in particular contributes by the daily transpiration to periodic pulsation of flows.

CONCLUSION

We were able to document the behavior of water level of Teplý potok during summer droughts in 2003–2007. By the behavior analysis of discharge regime of this stream, we took the view that the stream water resources have at least a dual nature. Kind of long-term declining trend we gave to groundwater. Temporary changes with 24-hour time step, we gave to hypodermal runoff and we described in detail the development of the daily pulse during dry periods.

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Analýza kolísání hladiny potoka v období sucha.

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Článek se zabývá popisem časového kolísání a vývoje průtoků potoka v urbanisticky nezatížené krajině, a to v období letního dlouhotrvajícího sucha. Hladina byla snímána kontinuálně několikrát za minutu v období několika po sobě jdoucích let. Při analýze se ukazuje, že průtoky vody v potoce lze jednoznačně rozdělit do dvou složek, a to přítoku povrchových a podpovrchových, zejména podzemních vod. Zatímco povrchová složka má jasnou čtyřiadvacetihodinovou periodu, složka podzemní ubývá rovnoměrně, téměř lineárně. Složka povrchová přidává k celkovému množství vody v potoce efekt minikulminace hladiny po západu slunce a prudký pokles po jeho východu. Jak okamžik zvýšení, tak i jeho celková velikost se s pokračujícími dny sucha vyvíjí. Zvýšení přichází stále později a je stále méně výrazné.

sucho; kolísání hladiny; výpar; respirace lesa; dynamika fluktuací

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