Water – soil – air temperature relationships in the Jalovecky creek catchment

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Beziehung der Wasser-, Boden- und Lufttemperatur im Einzugsgebiet Jalovecky Potok

Introduction

WFD-compliant methodologies to determinee typological classification schemes of physico-chemical elements for surface waters, need to assign limiting values of physico-chemical water elements for individual classes of water quality. Development of classification schemes in Slovakia is based on statistical processing of water quality data and subsequent expert evaluation (Pekarova et al., 2007). When defining limiting values of water temperature, we identified the problem of insufficient knowledge about the variability of water temperature, diurnally and for different surface water types. Water temperature was historically measured only at 7 a.m. in Slovakia (as well as in Central and Eastern Europe). Such a measurement represents daily minimum water temperature in streams of the upper Vah River basin, northern Slovakia (Figure 1.) Water temperature is also significantly dependent on altitude. Consequently research on water temperature variability in mountain streams was initiated. Its final objective is to elaborate a methodology to determine limiting values of water temperature for individual classes of water quality for different surface water sys-

Zusammenfassung

Der erste Teil des Beitrags widmet sich der Beziehung zwischen Wasser- und Bodentemperaturen sowie Wasser- und Lufttemperaturen im Einzugsgebiet des Jalovecky Creek im westlichen Teil der Hohen Tatra in der Slovakischen Republik. In der Periode 2007–2008 lagen die mittleren jährlichen Wassertemperaturen des Standorts Ondrasova bei 6.7 °C und die mittleren jährlichen Lufttemperaturen bei 7.9 °C. Die mittleren jährlichen Bodentemperaturen (zwischen 5 und 100 cm Tiefe) waren 9,4 bis 9,7 °C. Die maximal beobachtete Wassertemperatur im Jalovecky Potok betrug 20.1 °C und wurde am 3. Juli 2008 um 16:00 h gemessen. Lineare Regressionsmodelle und Logistische Mohseni Modelle wurden entwickelt, um die Beziehung zwischen maximaler und minimaler Wassertemperatur und zwischen Boden- und Lufttemperatur zu erklären. Der zweite Teil befasst sich mit der Erstellung eines Höhengradienten der Wassertemperatur im Gebiet Jalovecky Potok, welcher mit -0.3 °C pro 100 Meter für den November 2009 festgelegt wurde.

Schlagwörter: Wassertemperatur, Testeinzugsgebiete in der Niederen Tatra, Wasserrahmenrichtlinie.

Summary

The first part of this paper is devoted to relationships between water and soil temperatures, as well as between water and air temperatures in the Jalovecky creek catchment (the Western Tatra Mountains, Slovakia). For hydrological years 2007–2008 the mean annual water temperature at Jalovecky creek, Ondrasova (559 m a.s.l) was 6.7 °C, mean annual air temperature 7.9 °C at the meteorological station Ondrasova and mean annual soil temperatures 9.4–9.7 °C at depths 5–100 cm . The maximum water temperature for the observation period of 20.1 °C was measured on 3 July 2008 at 4 p.m. in the Jalovecky creek. The linear regression and logistic Mohseni models were established between the daily minimum and maximum water temperatures and soil and air temperatures. The second part of paper is devoted to determination of altitude gradient of water temperature in the Jalovecky creek catchment, was -0.3 °C per 100 m in November 2009.

Key words: Water temperature, experimental mountain basin, Jalovecky creek, Water Framework Directive 2000/60/EC.

tems in Slovakia. The objective of this study was to analyze the relationships between the water temperature *Tw*, soil temperature *TG* (at depth 5, 20, 50 and 100 cm) and air temperature *Ta* in the small mountain catchment of the Jalovecky creek. In the second part, we focused on determination of relationship between water temperature and altitude.

Study area

The Jalovecky creek catchment is situated in the Western Tatra Mountains, northern Slovakia and flows into the river Vah, which is the second longest river in Slovakia. The catchment is situated in the Tatra National Park (TANAP), which implies that human activities are restricted to tourism and the occasional removal of wood after calamities. The area of the whole catchment is 45 km^2. The catchment outlet is located at 556 m a.s.l.; the elevation of the highest peak is 2178 m a.s.l. The mean elevation for the whole catchment is 1166 m a.s.l. Mean annual temperature is 6.1 °C mm. Mean annual precipitation and mean annual runoff for the whole catchment is 1206 mm and 714 mm respectively. The catchment is divided into two parts with different natural characteristics – mountain and foothills. The mountain area is formed by crystalline rocks covered by Quaternary sediments. Mean elevation is 1500 m a.s.l. and the mean slope is 30°. It is densely forested (forest 44%, dwarf pine 31% of catchment area) and there are almost no other human activities, except for tourism. The foothills area is formed mainly by Paleogene rocks (impervious), which are covered by alluvium from the Jalovecky creek. The subcatchment is relatively flat. Coniferous forests and the dwarf pine cover about 32% of the catchment, urbanized zones, agricultural land and meadows cover 9%, 37% and 18%, respectively (HOLKO, KOSTKA, 2008).

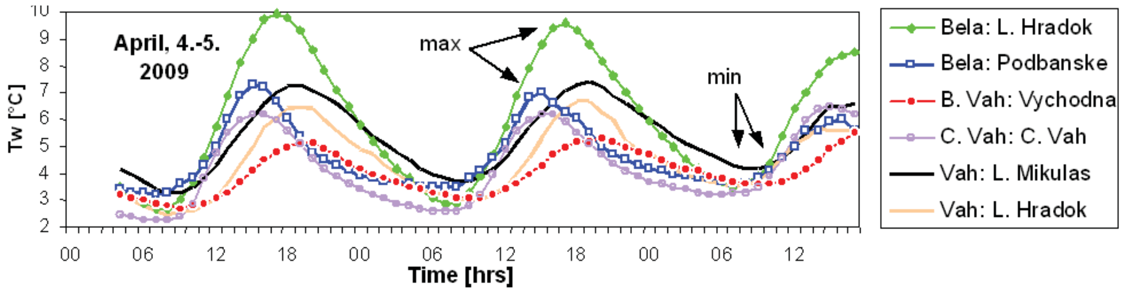

Figure 1: Example of the hourly water temperature *Tw* in different tributaries of the upper Vah River
Abbildung 1: Tagesgang der Wassertemperatur *Tw* an verschiedenen Nebengewässern des Vah-Flusses

Figure 2: Location of study area – Jalovecky creek catchment
Abbildung 2: Lage des Untersuchungsgebiets– Jalovecky Creek Einzugsgebiet

Data

Measurements of water temperature have had a long history in the former Czechoslovakia (Novicky et al., 2009; Pekarova et. al, 2008). Water temperature data were collected at either regular pre-determined intervals or intermittently. The Slovak Hydrometeorological Institute (SHMI) archives for water temperature in Slovak rivers contain temperatures measured manually at 7.00 a.m. since 1931. Electronic thermometers equipped with dataloggers were installed after 2005 to provide real-time measurements of water temperature.

Temperature data from two hydrological years 2007 and 2008 (November to October) were used for statistical analysis of the relationships between the water temperature and soil temperatures at different depths. Measured values of the soil and air temperatures were obtained from the meteorological station of SHMI at Ondrasova (560 m a.s.l.). The data has been recorded since 2006 in one-minute time intervals. The water temperature in the Jalovecky creek at the Ondrasova water gauge station (559 m a.s.l.) was measured by SHMI in 15-minutes time intervals since November 2005. Hourly water temperatures of the Jalovecky creek are measured by the Institute of Hydrology SAS (IH SAS) at the outlet of the mountainous area of the catchment (800 m a.s.l.) since 2002. In addition, we measured water temperatures in the Jalovecky creek (every 30 minutes) at 7 sites (Figure 2) at different altitudes (559–1110 m. a.s.l.) to analyze the altitude gradient of water temperature.

Results

Water-soil-air temperature relationships

From the correlation matrix and temporal variability of temperatures, it is obvious that the best correlation (R = 0.966) exists between the water temperature and soil temperature measured at the depth of 5 cm *TG5* (Figure 3). We have calculated the time delay between water (*Ta)* and soil temperatures. The cross-correlation scheme between *Ta* and *TG5* showed that the time delay of *TG5* is 1 day.

Generally, maxima of the water temperature in the Jalovecky creek occur at 3 p.m. and minima at 7 a.m. Therefore, we established the relationship between the water temperature (measured at 7 a.m. and 3 p.m.) and the average daily soil temperature using linear functions (Figure 4a) and between the daily air temperature using the logistic model

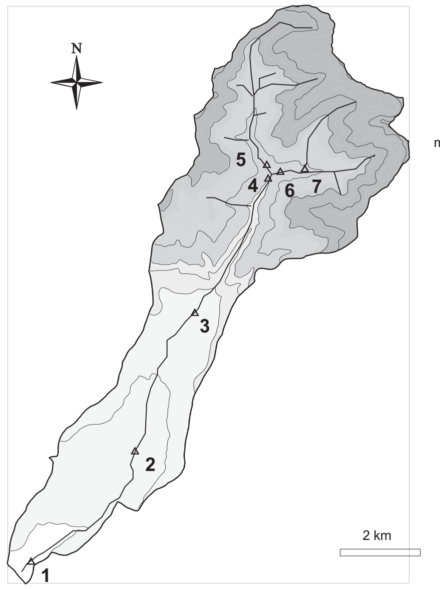

Figure 3: Stream-gauge stations and water thermometer location in Jalovecky creek catchment: 1–559 m a.s.l.–Ondrasova; 2–660 m a.s.l.–Jalovec; 3–860 m a.s.l.–Spring; 4–1000 m a.s.l.–Lisec; 5–1009 m a.s.l.–Bobrovec; 6–1015 m a.s.l.–Parichvost; 7–1110 m a.s.l.–Hlboky

Abbildung 3: Lage der Abfluss- und Wassertemperaturmessstellen im Jalovecky Creek Gebiet

of Mohseni et al. (1998) (Figure 4b). The differences between the daily minimum and maximum water temperatures during the hot summer days reached up to 5 °C.

In general, the water temperature of streams is significantly affected by the temperature of environment (air plus soil). According to previous calculations, there is a high dependence between water and air temperature (for linear function, correlation coefficient for *Tw* at 7 a.m is 0.85 and for *Tw* at 3 p.m is 0.89). We have calculated the time delay between water and air temperature. The cross-correlation scheme shows that the time delay is 1 day.

Dependence of water temperature on the altitude

The second part of the study is focused on water temperature analysis at different altitudes (from 559 up to 1110 m a.s.l.). Figure 5 (left) shows 30-minute measurements of water temperature at 7 sites located at different altitudes in the Jalovecky creek on 26 November 2009. The altitude gradient of daily mean water temperature was -0.3 °C per 100 m.

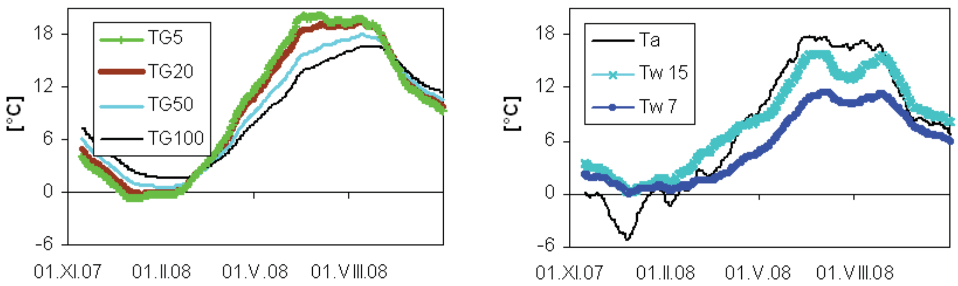

Figure 4: 30-day moving averages of soil temperatures *TG* measured at depths 5, 20, 50 and 100 cm (left); air temperature *Ta* and water temperatures measured at 7 a.m. and 3 p.m. *Tw7, Tw15* (right)

Abbildung 4: (Links): 30-Tage-Gleitmittelwerte der Bodentemperatur *TG* in 5, 20, 50 und 100 cm Tiefe. (Rechts): Lufttemperatur *Ta* und Wassertemperaturen um 7:00 h und 15:00 h *Tw7, Tw15*

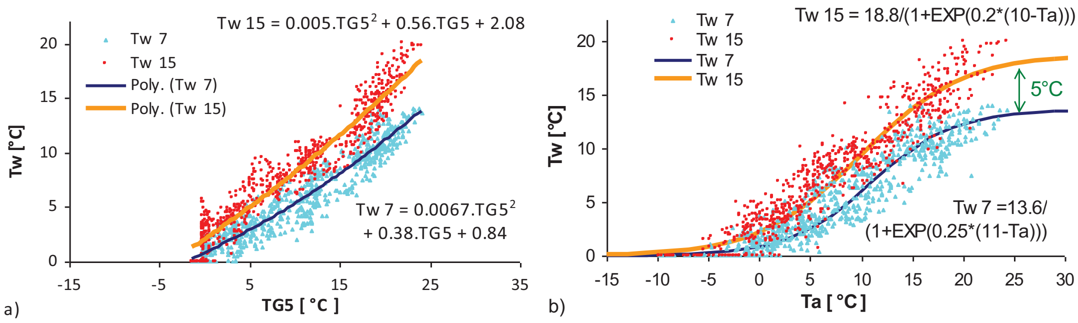

Figure 5: Measured and modeled maximum (*Tw* at 3 p.m.) and minimum (*Tw* at 7 a.m.) water temperatures a) model based on soil temperature *TG5* at depth 5 cm; b) model based on air temperature at meteorological station Ondrasova

Abbildung 5: Beobachtete und modellierte maximale (*Tw* um 15:00 h) und minimale (*Tw* um 7:00 h) Wassertemperatur unter Verwendung von a) Bodentemperatur *TG5* (5 cm Tiefe) und b) Lufttemperatur der Station Ondrasova

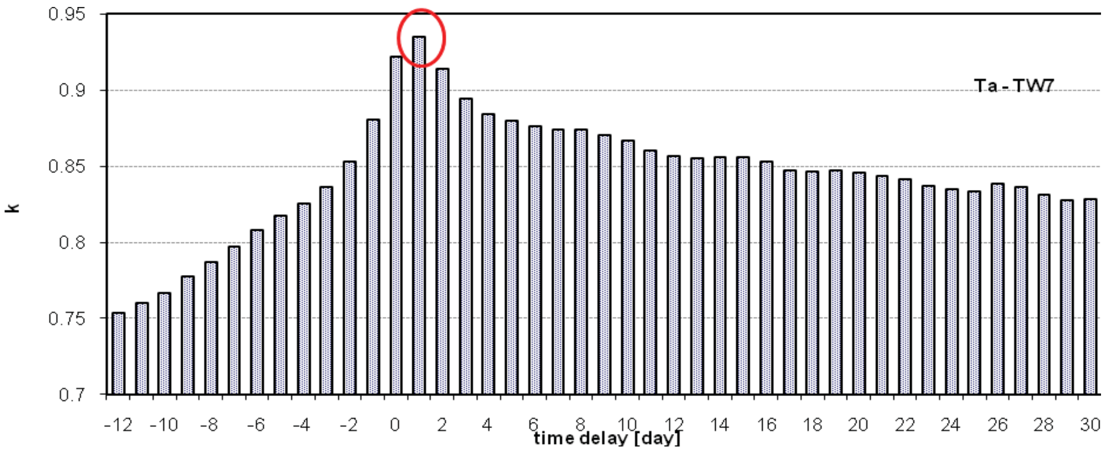

Figure 6: The cross-correlation scheme and time delay between water temperature at 7 a.m and air temperature

Abbildung 6: Kreuzkorrelationsdiagramm und Zeitversatz zwischen Wasser- und Lufttemperatur um 7:00 h

After one year observation we calculated altitude gradients of water temperature for each month and for two periods – winter and spring. The values of altitude gradients of water temperature in each month are listed in Tables 1 and 2. There is a negative correlation between water temperature and altitude. The altitude gradient of water temperature for the winter period (-0.03) is lower than the spring period (-0.4).

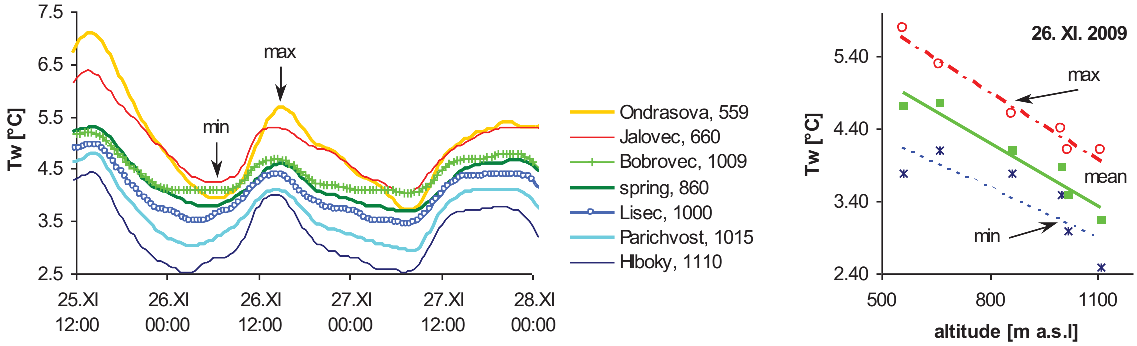

Figure 7: Water temperatures of the Jalovecky creek (*Tw*) at different altitudes on 26 November 2009, 2-hours moving average (left); relationships between minimum, maximum and mean daily water temperatures and altitude in the Jalovecky creek catchment (right)
Abbildung 7: Wassertemperaturverlauf am Jalovecky Creek in verschiedenen Höhenbereichen (links); Höhengradient der minimalen, maximalen und mittleren Tageswassertemperatur im Jalovecky Creek Gebiet

Table 1: Altitude gradients of water temperature for December, January and February (monthly winter period)
Tabelle 1: Höhengradienten der Wassertemperatur für die Monate Dezember bis Februar

	winter period		
altitude gradient	-0.03		
month	**December**	**January**	**February**
altitude gradient	*-0.12*	*-0.04*	*0.06*

Table 2: Altitude gradients of water temperature in months of March, April and May (spring period)
Tabelle 2: Höhengradienten der Wassertemperatur für die Monate März bis Mai

	spring period		
altitude gradient	-0.4		
month	**March**	**April**	**May**
altitude gradient	*-0.2*	*-0.54*	*-0.56*

Conclusions

There are several conclusions resulting from our analysis:

At first, we decided to analyze the relationship between water temperature and other media (air and soil) in the small mountain catchment of the Jalovecky creek. There is a high dependency between water and air temperature (for minimun (*Tw7*) R = 0.85, for maximum (*Tw15*) R = 0.89). We have calculated the time delay between water and air temperatures. The cross-correlation scheme shows that the time delay is 1 day.

Water temperature measured in Slovakia at 7 a.m. is often (incorrectly) considered to represent mean daily water temperature. Our analysis revealed that it represents the minimum daily water temperature.

The difference between maximum and minimum daily water temperature of the Jalovecky creek can reach up to 7 °C during sunny summer days. Differences between average minimum (5.6 °C) and average maximum (8.3 °C) daily water temperature at Ondrasova during the period November 2006–October 2008 was 2.7 °C. According to the Mohseni function, this difference in the air temperature of 20 °C is 5 °C on average (Figure 5).

This fact is very important for the estimation of the ecological limit values of water temperature according to WFD (2000/60/EC). The ecological water temperature limits derived from temperature measured at 7 a.m. represent minimal daily water temperature.

The final part of the paper was devoted to dependence of water temperature on altitude in mountainous areas. Initial

Table 3: Monthly limits of the water temperature in the pristine Bela River at Podbanske station (at 7.00 a.m.), 922 m a.s.l. for high ecological status determined from the historical data series, according to PEKAROVA et al. (2011)
Tabelle 3: Monatliche Schwellenwerte der Wassertemperaturen für das unbeeinflusste Bela Flussgebiet mit sehr gutem ökologischen Zustand

Month	1	2	3	4	5	6	7	8	9	10	11	12
Tw °C	5.3	4.7	5.6	6.6	7.4	10.1	9.4	9.9	8.2	7.6	6.8	6.3

results showed a significant negative correlation between water temperature and altitude. Temperature gradient in winter period was –0.03 °C per 100 m of altitude and in spring was –0.4 °C.

Our final objective is to elaborate a methodology to determine limiting values of water temperature for individual classes of water quality for different surface water bodies in Slovakia. To reach our final objective, several tasks need to be completed. These include combining historical water temperature data measured at 7 a.m. at one station with hourly data series observed in several different altitudes.

For example, in PEKAROVA et al. (2011) monthly limits of the water temperature were determined from the historical 50-year daily water temperature records. These values were determined for Bela River at station Podbanske (922 m a.s.l., High Tatra mountainous). Now, we have to spread those values for differed altitudes.

Acknowledgement

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