

VARIATION IN LITHUANIAN RIVER WATER TEMPERATURES

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Abstract. In this article the variation in Lithuanian river water temperatures of the warm season (May–October) of the year for both the whole observation period (1945–2008) and the latest standard normals period (1961–1990) is analysed. According to 1961–1990 periods' standard normals data, the map of river water temperature distribution was compiled. Also, the correlation analysis between the warm season's river and lake water temperature as well as air temperature was performed.

Keywords: river, water temperature, water gauging station, warm season average, variation.

1. Introduction

The thermal regime of a water body is of interest to a wide variety of scientists and water users, because temperature of a water body directly affects many physical, chemical and biological characteristics of water (Smith 1981).

Changes in water temperature are linked to changes in water quality, especially dissolved oxygen concentration. Oxygen is less soluble in warmer water and this can affect aquatic life. Thermal regime influences aquatic organisms in terms of diversity of species, abundance, distribution, growth rate, tolerance to diseases et al (Caissie 2006). Aquatic species live in water of specific temperatures. Changes in long-term temperature average may cause differences in the species of ecosystem. With extreme water temperature changes, many organisms will die (Waterwatch Australia.... 2002).

Most communities living in freshwater ecosystems are cold-blooded and will be sensitive to changes in the water temperature (Conian *et al.* 2005). River water temperature is especially important for the salmon and trout, which are sensitive ecological indicator species of substantial commercial importance (Langan *et al.* 2001).

In hydrology, water temperature is not the main characteristic of river run-off; however, the component of water balance – evaporation is determined by water temperature of the water body and other factors. However, in hydro-ecological research and practice, especially where it relates to water bodies' (including rivers) nutritional base, fish spawning, self-purification, hydro-ecologic systems and other issues, the hydrothermal regime of biotopes is one of the prevailing factors (Lietuvos ekologinis... 1999; Galvonaitė and Valiukas 2005; Jablonskis 1986). In addition,

the river ice phenomena and hydrological regime in spring are closely related to the water and air temperatures.

The thermal regime of Lithuanian rivers is not sufficiently generalized. Until now, most attention was paid to the water temperature of the River Nemunas and to the research of the thermal regimes of the river reaches below dams (Rimavičiūtė 2000).

This work aimed to investigate Lithuanian rivers thermal regime and its determinants as well as to analyse the character of the temporal and spatial variation of Lithuanian river water temperature. Because of the large amount of statistical data, in this article are analysed only the average water temperatures of the warm period (May–October), since the most intensive hydrological and hydro-biological processes in water bodies take place at warm period.

2. Data and Methodology

The measurement of water temperature in Lithuania was started in 1928 in the River Nemunas at Kaunas. Ice cover observations were performed since 1811 in the River Nemunas at Smalininkai. The systematic research of the thermal regimes of river water were started in 1945 in most of the water gauging stations (WGS) of Lithuanian Hydrometeorological Service that were working at that time. Currently the temperature of water is measured in 139 WGS that are established on 84 rivers. Lithuanian Hydrometeorological Service publishes water temperature data in annual Hydrological Yearbooks. River water temperature data of 1945–1957 periods was corrected according to archival data.

An average water temperature for each year's warm season was calculated by calculating a common temperature mean for 6 months (May–October). For each WGS

the statistical parameters of multi-annual mean of warm season's water temperature were calculated for both the whole observation period and the standard normals period (1961–1990). These parameters are presented according to the thermal groups of rivers in the work (Jablonskis and Jurgelėnaitė 2010). In this paper the analysis of the initial data, which is presented in the work (Jablonskis and Jurgelėnaitė 2010), is continued.

3. Results

3.1. Lithuanian river water temperature

Water heats up directly from the solar radiation and air. Due to the latitudinal distribution of total radiation as well as the balance of radiation, the distribution of water temperature in a specific territory should be even. However, because of the effect of such factors as cloud cover, horizontal transport of air masses, evaporation as well as groundwater feeding, the differences in the thermal regimes of water occur not only among rivers in the same physical-geographic regions, but also in the different reaches of a single river.

During this study it was found that the multi-annual mean of the warm season's water temperature in Lithuanian rivers varies from 7.6 °C (Creek Smardonė at Likėnai) to 16.7 °C (the branch of the River Nemunas delta – Rusnė at Panemunė). Thus, warm season water temperature contrasts of the country's rivers reach 9.1 °C based on multi-annual means.

After analyzing rivers, which have long water temperature data sets (41 WGS) covering standard period (1961–1990), it was determined that for the standard normal period average warm season's river water tem-

perature varies from 12.3 °C (Vilnia at Santakai) to 16.1 °C (Šešupė at Dolgoje). Thus, the contrasts based on standard norms reach 3.8 °C. The data series of creeks that have the lowest water temperature (Smardonė, Verdenė) do not include the standard normal period.

It could be noted that the biggest rivers such as the River Nemunas and its biggest tributaries (River Neris, Nevėžis, Šešupė) as well as the River Mūša, Nemunėlis, Venta have the highest water temperature.

The coldest rivers are: the River Merkys, its tributary Ūla, the River Neris' tributary – Vilnia, the River Rešketa, which flows through Žemaičiai Highland, as well as other 13 small rivers. These rivers are small streams (except for the River Merkys); however, water permeable sand soil is prevalent in their watersheds. Also, the rivers are relatively abundantly fed by cold groundwater and spring's water. 75 % of Merkys, 89 % of Ūla, 92 % of Vilnia and 59 % of Rešketa watersheds are covered by sandy soils. Usually, sandy watersheds of rivers are covered by forest that shades the stream. However, particularly cold are the streams Verdenė and Smardonė, which are fed by cold springs of karst region and whose average water temperature over the warm season (May–October) is lower than 8 °C.

The variety of Lithuanian river water temperature could be evaluated by the map of river water temperature isolines (isotherms) presented in Fig 1.

The map is compiled according to the WMO climatological standard period (1961–1990) water temperature averages (normals) for 41 WGS. If compared to the multi-annual average (\bar{t}_n), standard normals (\bar{t}_{30}) are approximately 0.15 °C or 1 % lower.

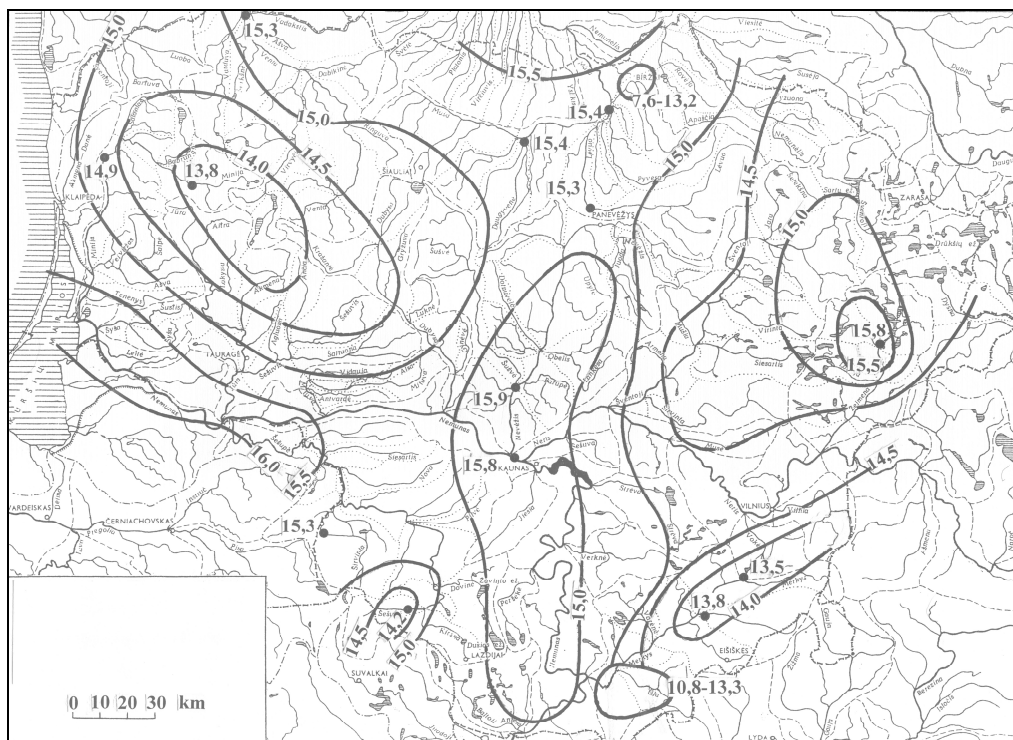


Fig 1. The map of the warm season's average multi-annual water temperature of Lithuanian rivers (t_{V-X} °C)

When drawing water temperature isolines, the means of shorter datasets were considered as well. The step of the temperature \bar{t}_{30} isolines is $\Delta t = 0.5^\circ\text{C}$, because it was ascertained that on the same river and between separate rivers water temperature is statistically (at $\alpha = 0.05$) different, than $\Delta t \geq 0.5^\circ\text{C}$. According to such difference, in the work (Jablonskis and Jurgelėnaitė 2010) all the researched rivers were divided into separate groups. In the map the 15°C isotherm is prevalent. It could be treated as the main or the central one. It reflects the territorial mean of all the researched rivers, which is $\bar{t}_{30} = 14.88^\circ\text{C}$ and which has a standard deviation of $S_{30} = 0.92^\circ\text{C}$. Thus, based on the $t = 15.0^\circ\text{C}$ isotherm, it is possible to consider about the thermal capacity of the river that flow through the Lithuanian territory: when $t > 15.0^\circ\text{C}$ – it is a warm water river, when $t < 15.0^\circ\text{C}$ – cool water river. 15°C isotherm clearly surrounds Žemaičiai Highland, goes through 1 Lithuanian Middle Lowland and encircles the lake part of Aukštaičiai Highlands. The 14°C isotherm is prevalent in Žemaičiai Highland and Southeast Lithuania. Thus, the warmest water (15°C – 16°C) is in Southwest and Middle Lithuania (in the watersheds of the River Nemunas and Mūša). In the map it is also possible to notice the influence of other local factors: groundwater inputs, lakes, rate of stream flow, etc. The “islands” having low water temperature highlight on the map. One of them is a karst region between town Biržai and town Pasvalys, where streams Smardonė, Verdenė, Tatula, Įstras, having water temperature of only 7.5°C – 13.8°C , flow. Other region, it is the lower reaches of the River Merkys at Puvočiai and its tributaries Ūla and Skroblus, which have water temperature of 10.8°C and 13.3°C . Thus, according to this map it is possible to determine the water temperature of the river which has not been investigated.

3.2. The correlation of river water temperature variation

What determines the thermal regime of the country’s river water, its differences between the separate rivers and different reaches on the same river, is a poorly researched

issue. Maintaining that river water temperature depends only on climatic factors would be incorrect, because climatic changes in Lithuanian territory are not significant (due to its small area). However, it is not possible to completely ignore the influence of climatic factors to river water temperature. In fact, the solar radiation, in contact with the surface of a water body or ground surface (both of which also exchange heat), forms the basic thermal regime of water bodies, while the variability of this regime is influenced by other factors, including local ones.

In order to ascertain how the water temperature of different rivers is self-related we performed correlation analysis. 13 rivers, which have different temperature regimes and whose warm season’s average water temperatures are between 16.0°C (Nemunas at Druskininkai) and 13.2°C (Merkys at Puvočiai), were selected [1]. Between 13 WGS water temperatures of 1961–1990 period, the pairwise ($n = 78$ pairs) correlation coefficients r were calculated (Table 1).

In order to analyse these coefficients, it is firstly important to note that all the coefficients are statistically significant, since they were calculated employing $n = 30$ data series. Therefore, it is possible to maintain that the multi-annual change of river water temperature is statistically similar. Knowing that the statistical mean is closest to the real one, it is calculated for 78 WGS pairs and is equal to $\bar{r}_{78} = 0.87$. It can characterize the correlation of the multi-annual water temperature variation of all the researched rivers. This is a high indicator, which was calculated using $n = 78$ data.

Another indicator is a deviation from the average (standard deviation S) or a more simple value – variation width A (the difference between the largest and the smallest values in the data set). According to the r_{xy} data, $A = 0.96 - 0.76 = 0.20$. It could be noticed that the best synchronicity of water temperature is observed between the River Minija and the River Venta ($r = 0.96$) flowing through the slopes of Žemaičiai Highland. The lowest synchronicity ($r = 0.76$) of water temperature is between the River Jūra, which runs through the Žemaičiai Highland, and the upper reaches of River Šešupė, which begins in Baltija Highlands.

Table 1. The warm season’s (May–October) river water temperature correlation coefficients r between WGS over 1961–1990 period

River	WGS	Average water temperature	Žeimena Kaltanėnai	Šušvė Josvainiai	Jūra Tauragė	Venta Leckava	Lėvuo Pasvalys	Minija Kartena	Šešuvis Skirgailai	Šventoji Ukmergė	Jūra Pajūris	Šešupė Kalvarija	Dubysa Lyduvėnai	Merkys Puvočiai	Pair means
Nemunas	Druskininkai	16.0	0.85	0.85	0.82	0.90	0.92	0.89	0.79	0.90	0.86	0.85	0.85	0.89	0.86
Žeimena	Kaltanėnai	15.8		0.80	0.80	0.86	0.92	0.84	0.88	0.88	0.81	0.86	0.84	0.84	0.85
Šušvė	Josvainiai	15.7			0.84	0.91	0.90	0.88	0.83	0.86	0.88	0.84	0.88	0.85	0.86
Jūra	Tauragė	15.5				0.91	0.84	0.93	0.90	0.83	0.94	0.76	0.89	0.81	0.86
Venta	Leckava	15.3					0.92	0.96	0.90	0.87	0.93	0.84	0.92	0.89	0.90
Lėvuo	Pasvalys	15.1						0.92	0.89	0.91	0.85	0.91	0.94	0.92	0.90
Minija	Kartena	14.9							0.90	0.89	0.92	0.81	0.93	0.88	0.90
Šešuvis	Skirgailai	14.7								0.79	0.87	0.85	0.87	0.85	0.86
Šventoji	Ukmergė	14.6									0.84	0.83	0.93	0.89	0.87
Jūra	Pajūris	14.6										0.77	0.87	0.83	0.86
Šešupė	Kalvarija	14.2											0.90	0.90	0.84
Dubysa	Lyduvėnai	14.2												0.90	0.89
Merkys	Puvočiai	13.2													0.87

The water temperature of the River Lėvuo at Pasvalys has the highest correlation with the temperature of the remaining rivers ($r = 0.90$), slightly lower – the River Šešupė at Kalvarija ($r = 0.84$) and the lake Žeimena at Kaltanėnai ($r = 0.85$). Among the warmer water rivers, which have an average temperature of 14.88°C , the variation of temperature is more correlated ($r = 0.88$) than the variation of cooler water rivers ($r = 0.85$). Empirical coefficients (r_{xy}), calculated from $n = 30$ data series, are statistically significant and close to the real ρ .

These comparisons indicate that the synchronicity of the river water temperature multi-annual variation should depend on how far away the rivers are from each other. It can be considered that it is related to the change of climatic background depending on the geographic position of the location. Therefore, let's try to evaluate this statistically. i.e. let's analyze the relationships between the river water temperature correlation coefficients and the distance between WGS of those rivers – L . i.e. $r_{xy} = f(L)$. The graph is presented in Fig 2.

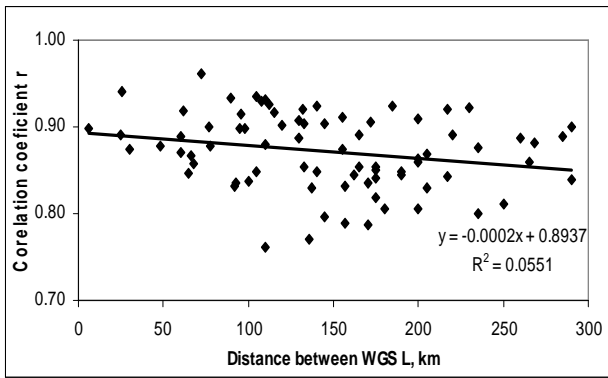


Fig 2. Relation between river water temperature correlation (r) and distance between WGS (L , km)

Formalizing the relationship $r_{xy} = f(L)$, i.e. making the correlation function, it was found that the correlation coefficient of this relationship is $r_{xyL} = -0.23$. Although the obtained value is not significant, but it indicates that the synchronicity of the river water temperature multi-annual variation between WGS is inversely proportional to the distance between them. However, based on the Student's t -test, it can be assessed that the correlation coefficients of relation of general completeness is $\rho \neq 0$, because

$$\hat{t} = r_{xyL} \sqrt{\frac{(n-2)}{(1-r_{xyL}^2)}} > t_{\alpha, n-2} \quad (1)$$

i.e., $|\hat{t}| = 2.184 > t_{0.05, n-2} = 2.00$. Therefore, the relationship shown in Fig 2 could be approximated by a simple linear relationship $r_{xyL} = 0.89 - 0.0001L$. For example, than $L=300$ km. $r_{xyL} = 0.89 - 0.03 = 0.86$.

After performing the analysis of water temperature data, it could be maintained that the multi-annual variation of the Lithuanian river water temperature is synchronic and almost independent of the distance between them. From the climatic viewpoint all of the researched rivers could be ana-

logues to each other. The similarity of the multi-year variation of river water temperature in terms of both spatial and temporal is determined by little changing climatic background. The different level of river water heating is influenced by local physical-geographic factors. The most prevalent are river groundwater feeding, lakes and reservoirs, the orographic position of river, the rate of stream flow, river length, a shadiness of riverbank, etc. The influence of some of these factors is presented in the work (Jablonskis and Jurgelėnaitė 2010).

3.3. The correlation of the multi-annual variation of the Lithuanian river and lake water temperature and air temperature

The analysis of such character of subject is interesting because from the more researched element a decision about the less researched element's state could be made. In this paper the common correlation field of river, lake and air temperatures was examined. The correlation coefficients are presented in Table 2. All the correlation coefficients are statistically significant. Lake water temperature is most closely related to air temperature ($\bar{r} = 0.90$), less correlation ($\bar{r} = 0.88$), is between the multi-annual mean of river water temperature and air temperature in the researched three meteorological stations (Vilnius, Šiauliai and Telšiai). The correlation of river and lake water temperature variation could be evaluated by ($\bar{r} = 0.86$) correlation coefficient.

The multi-annual means of hydro-meteorological elements were found according to data of water gauging stations and meteorological stations for 1961–1990 period:

1. River water temperature (41 WGS) $\bar{t}_r = 14.9^{\circ}\text{C}$.
2. Lake water surface temperature (21 WGS) $\bar{t}_l = 15.4^{\circ}\text{C}$.
3. Soil surface temperature (8 MS) $\bar{t}_s = 15.4^{\circ}\text{C}$.
4. Air temperature (19 MS) $\bar{t}_a = 13.2^{\circ}\text{C}$.

We can see that the average multi-annual warm season's river water temperature is 1.7°C higher than air temperature and that it is 0.5°C lower than the temperature of soil surface and the water surface of lakes. This indicates that during warm (vegetation) period, air is heated by the soil surface as well as by the warm water of water bodies, including rivers.

The multi-annual variations of river water temperature of some rivers, which have different rate of stream flow as well as variation of air temperature are presented in Figure 3.

The curves in Figure 3 show that water temperature during the 1945–2008 period changed in a relatively synchronic way despite of rate of stream flow of the river. In addition, it coincides with the multi-annual variation of air temperature, especially of Vilnius MS, fairly well. The wave-shaped integral curves show that multi-annual trends of river water temperature were changeable and had cyclic character during the researched period of 64 years.

Table 2. The warm season's multi-annual variation of Lithuanian river and lake water temperature and air temperature – correlation coefficients r (1961–1990)

Water body	Measuring station	Standard normals	Ūla Zervynos	Šventoji Ukmergė	Dubysa Lyduvėnų	Venta Leckavos	Rešketa Gudelių	Lake Žeimenys	Lake Dusia	Vilnius MS	Šiauliai MS	Tešiai MS
River Nemunas	Druskininkai	16.0	0.74	0.92	0.85	0.90	0.77	0.87	0.84	0.91	0.92	0.87
River Ūla	Zervynos	12.8		0.87	0.79	0.80	0.83	0.75	0.77	0.93	0.77	0.72
River Šventoji	Ukmergė	14.6			0.91	0.87	0.80	0.86	0.86	0.93	0.83	0.86
River Dubysa	Lyduvėnai	14.2				0.92	0.75	0.87	0.87	0.89	0.91	0.90
River Venta	Leckava	15.3					0.81	0.87	0.81	0.87	0.86	0.87
River Rešketa	Gudeliai	13.2						0.61	0.62	0.83	0.68	0.74
Lake Žeimenys	Kaltanėnai	16.0							0.88	0.85	0.95	0.95
Lake Dusia	Meteliai	14.9								0.84	0.89	0.89
	Vilnius MS	13.1									0.90	0.84
	Šiauliai MS	13.1										0.90

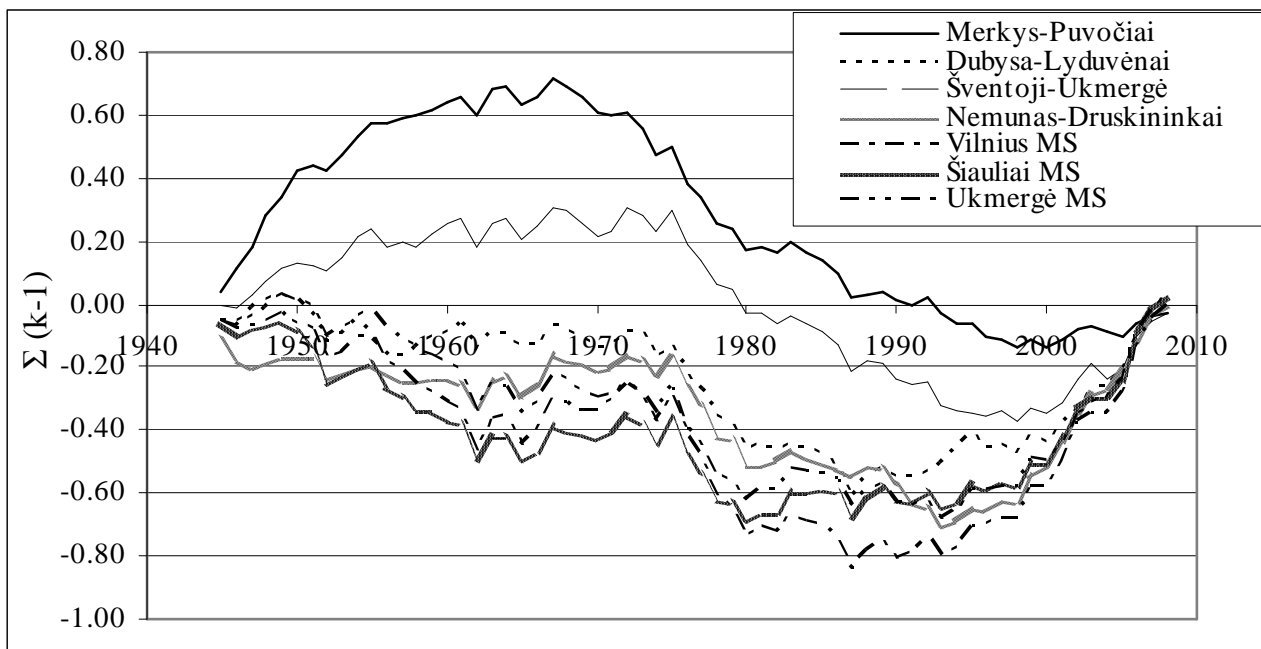


Fig 3. The trends (integral curves) of variation of river water temperature and air temperature of warm period (May–October) of the year over 1945–2008

The water temperature of unexplored rivers can be determined from the isotherm map, coordinating it with water temperature of adjacent river and air temperature of neighbouring meteorological station.

4. Conclusions

1. The analysis of water temperature of 84 rivers' 139 WGS allows to assess the thermal regime of the country's rivers.
2. The isoline (isotherm) map of the warm season's (May–October) river water temperature, which was compiled according to the 1961–1990 global standard normals data for 41 WGS, well reflects the river thermal regime that is determined by climatic factors and local condition.
3. It was ascertained that the water temperature of the researched rivers' is on average 1.6 °C higher than air temperature and is on average 0.5 °C lower than the soil surface temperature as well as the temperature of the water surface of lakes.
4. The variation of water temperature of researched rivers' and air temperature of meteorological stations' is statistically identical and has the character of multi-annual cyclical fluctuation.
5. The water temperature of unexplored rivers' could be determined from the isoline map, which is presented in Figure 1, adjusting it with the water temperature of neighbouring rivers and meteorological station air temperature as well as the local factors, influencing it.

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