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Influence of climate variability on water resources in the Bulgarian South Black Sea basin

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Abstract The South Black Sea basin in Bulgaria was selected as the study area. The region is of agricultural and forest importance for the country. The irrigation water demand increases in summer when most of the rivers in the region have low flows. The purpose of this research is to assess the variability of hydro-meteorological conditions in the study catchments. Long-term data (1952–2002) from some hydro-meteorological gauging stations, which are located in the study catchments, were used. In order to evaluate the influence of climatic factors on the water resources, the warm and humid conditions were analysed. Application of several statistical tests demonstrated that there are changes in runoff which are not caused by man's activity. The features of the variations of these hydro-meteorological elements and their inherent trends are determined. The results of this study show that runoff has decreased considerably all over the study region in recent years. The significant tendency to a gradual reduction of runoff in the region is due to considerably decrease of the precipitation and increase of temperature.

Key words climate change; runoff; warm and humid conditions; water resources

INTRODUCTION

The influences of climate variability and change on water resources are displayed in every sector of the water system. Water resources are affected by changes in precipitation as well as by temperature, humidity, wind and sunshine. Climate variability provides the driving force for hydrological variability in the landscape. However, the landscape has a modifying influence on the distribution of water in time and space in such a way that water quantity, as measured at any single point in the surface water network on the landscape, is not necessarily a direct result of recent meteorological events. The routing of water through the landscape transforms linear meteorological inputs into nonlinear hydrological outputs. The runoff is the most important and direct water resource. The effects of climate change on the hydrological cycle and on the runoff behaviour of river catchments have been discussed in a series of papers and reports (e.g. Loaiciga *et al.*, 1996; Sefton & Boorman, 1997; Schriner & Street, 1998; Arnell *et al.*, 2001).

The purpose of this research project is to assess the variability of hydro-meteorological conditions in the Bulgarian South Black Sea basin.

DATA USED

To investigate possible impacts of climate variability on runoff, the authors have used long-term data (1952–2002) from several hydrological (Razhitsa, Kameno, Prohod, Svetlina, Fakiya, Zidarevo, Veselie, Zvezdets and Gramatikovo) and meteorological (Aytos, Burgas, Grudovo, Tsarevo and Malko Turnovo) gauging stations which are located in the study catchments. Before use, the streamflow data was carefully reviewed and adjusted. For a number of reasons, the published flow may not represent the data actually required by the analyst. Storage reservoirs, diversions, levees, etc., can produce changes in either total flow volume, or rate of flow, or both. In this case an adjustment of the record was done by use of the double-mass analysis at given stations to test the consistency of data.

The modifications of the natural flow regime (storage, withdrawals, diversions etc.) in the rivers it is due to construction of hydro-technical installations, agricultural development and growing urbanization. Therefore during the determination of the influence of climate change on streamflow, it is necessary to choose a basin where the human activity is minimal. The study region corresponds to this condition.

Statistical techniques were used to assess the hydro-meteorological conditions in the study region with respect to climate variability, and also to draw inferences about the future prospects for hydrological processes and to determine whether trends identified in the observed data are consistent.

DESCRIPTION OF STUDY AREA

The South Black Sea basin covers an area of 5457 km^2. It is bordered by the Black Sea to the east, by the catchments of the Kamchia River and Dvoynitsa River to the north, by the Turkish border to the south, and by the Tundzha River catchment to the west. Small and independent rivers with small catchment areas debouch to the Black Sea. The bigger rivers in this region are the Veleka River (995 km^2) and Sredetska River with (985 km^2). The Sredetska River has 19 tributaries. The remaining rivers cover an area of between 133 km^2 (Diavolska River) and 641 km^2 (Fakiyska River). The longer river is the Veleka (147 km); the stream length of the rest of the rivers varies between 32 km (Aytoska River) and 69 km (Sredetska River). The more important rivers in this region between the Kamchia River and the Turkish border are the Dvoynitsa, Hadzhiyska, Aheloy, Aytoska, Rusokastrenska, Sredetska, Fakiyska, Ropotamo, Diavolska, Veleka and Rezovska rivers (Fig. 1). The topography is characterized by lowlands (0–100 m a.s.l.) which cover the eastern and middle parts of the region and the coast, low plains and low mountainous area. The higher parts are in the north and south; Strandja Mountain (up to 600–700 m a.s.l.) and the western regions are low (up to 400 m a.s.l.). The streams that discharge to the Black Sea have rather diverse forest vegetation. The north and south parts include coppice wood, oak and beech communities, but coppice woodland prevails. The middle part is characterized by a lack of forest; small coppiced woods do occur but mainly in the upstream.

According to the climatic classification of the country, the study region belongs to the Black Sea climate sub-type of the Continental Mediterranean climate. The weather

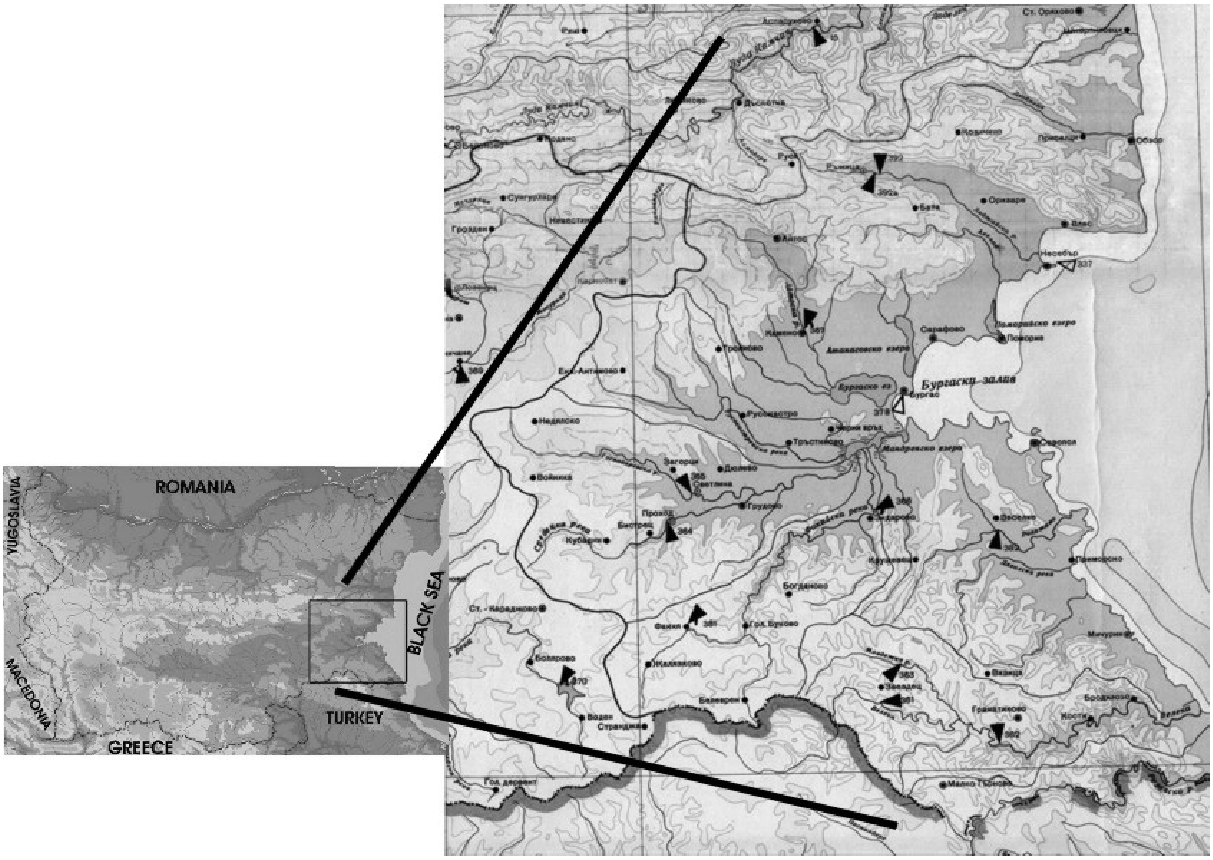

Fig. 1 Location of the study region.

generated from the west and north has an influence; the Black Sea influences weather from the east and the Mediterranean influences weather from the south. The southeastern region climate is mainly transitional Mediterranean climate. Local climatic differences are due, above all, to the proximity of the Black Sea, which warms up the coastal zone in winter, and cools it, especially in spring. The topography, particularly the mountains to the south (Strandja Mountain), play an important role in the distribution of precipitation. The territory concerned is one of the sunniest parts of Bulgaria. The considerable values of the radiation balance, positive for all months, fix the high thermal level. The average temperatures for all months are positive. The highest average monthly temperatures in winter, in Bulgaria, are observed here (along the southern Black Sea coast, 3–4°C in January).

RESULTS AND DISCUSSION

We first examine the long-term variability of the runoff to investigate any changes occurring in its characteristics. After that, we analyse the long-term variation of the precipitation. The runoff regime in the studied catchments is characterized by considerably variability. Table 1 shows the mean annual runoff (Q_{mean}) for the main gauging stations, as well as the statistical parameters (standard deviation, σ, coefficient of variation, Cv and skewness, Cs) and the extreme values for the studied period. The

Table 1 The basic statistical parameters for the catchments.

River, gauging station	Area, A (km^2)	Annual values Q_{mean} (m^3 s^{-1})	$\overline{Q}_{\min}^{annual}$ (m^3 s^{-1})	$k=\frac{\overline{Q}_{\min}}{\overline{Q}}$	$\overline{Q}_{\max}^{annual}$ (m^3 s^{-1})	σ (m^3 s^{-1})	Cv	Cs
Hadzhiyska River at Razhitsa	50.1	0.125	0.008	0.065	0.470	0.105	0.843	1.279
Aytoska River at Kameno	243.2	0.475	0.045	0.095	1.263	0.326	0.685	1.016
Sredetska River at Prohod	335.8	1.558	0.115	0.074	3.760	0.962	0.617	0.771
Gospodarevska River at Svetlina	387	1.158	0.221	0.191	2.260	0.621	0.536	0.234
Fakiyska River at Fakiya	100.5	0.562	0.134	0.238	1.456	0.310	0.552	0.940
Fakiyska River at Zidarovo	628.6	3.816	1.120	0.293	13.380	2.218	0.581	2.261
Ropotamo River at Veselie	190	1.128	0.330	0.293	3.899	0.744	0.660	1.867
Veleka River at Zvezdets	331.1	3.210	0.964	0.300	7.075	1.482	0.461	0.880
Veleka River at Gramatikovo	770	7.694	1.657	0.215	20.776	4.124	0.536	1.226

Q_{mean} is the mean annual runoff; $\overline{Q}_{\min}^{annual}$ is the annual runoff minimum; $k=\frac{\overline{Q}_{\min}}{\overline{Q}}$ is the relative mean monthly runoff minimum; $\overline{Q}_{\max}^{annual}$ is the annual runoff maximum; σ = standard deviation; Cv = coefficient of variation; Cs = skewness.

annual runoff minimum in the catchments of the southeastern part of Bulgaria varies from 0.008 m^3 s^{-1} (Hadzhiyska River at Razhitsa) to 1.657 m^3 s^{-1} (Veleka River at Gramatikovo) (Table 1).

In order to evaluate the impact of climate variability on river runoff in the south-eastern Bulgarian catchments, the warm and humid conditions during the last 50 years were analysed. To examine the temperature and precipitation variability, the time series of their anomalies was obtained (Figs 2 and 3). The anomalies show the large variability of the meteorological elements and their tendencies. During the last decade there is a tendency for temperature increase (Fig. 2) and a very noticeable rainfall decrease (Fig. 3).

The temperature increase in the catchments is more apparent in the mountain areas (Strandja Mountain) and weaker in the Black Sea coastal zone. The precipitation decrease in the last years is more noticeable in the Strandja region compared to the rest of the study area.

The high temperature and low precipitation condition in the region are conducive to drought, so producing unsuitable conditions for water supply. To understand the different impacts that the precipitation deficit has on groundwater, reservoir storage, soil moisture, snowpack, and streamflow, the Standardized Precipitation Index (SPI) was used.

The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water

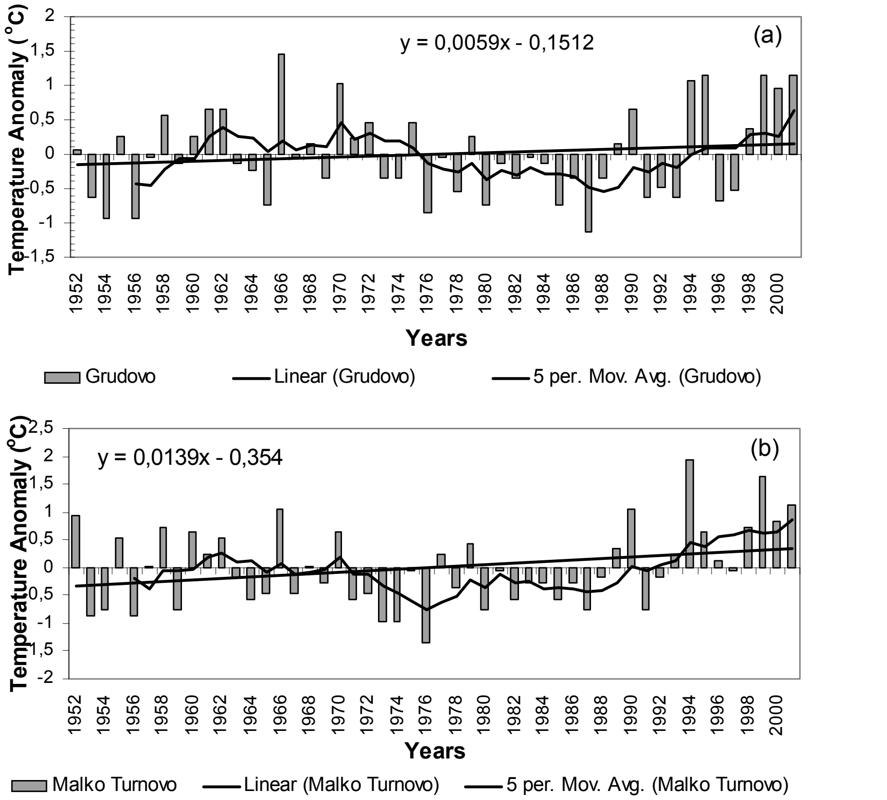

Fig. 2 Temperature anomalies at the (a) Grudovo and (b) Malko Turnovo stations.

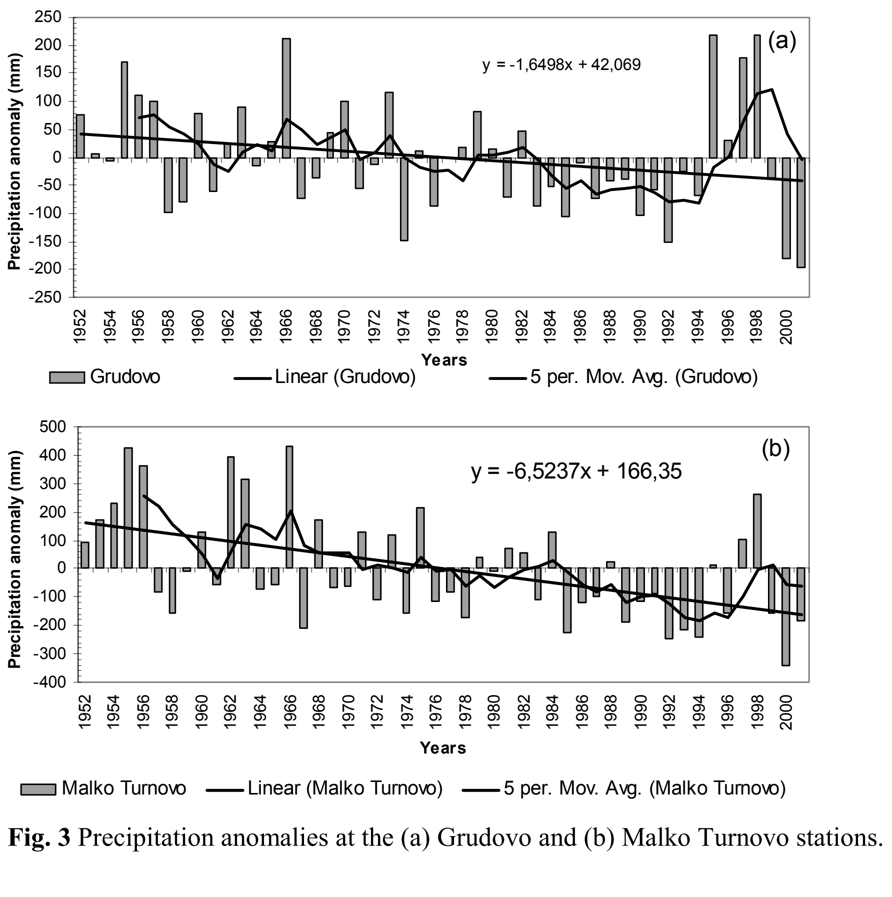

Fig. 3 Precipitation anomalies at the (a) Grudovo and (b) Malko Turnovo stations.

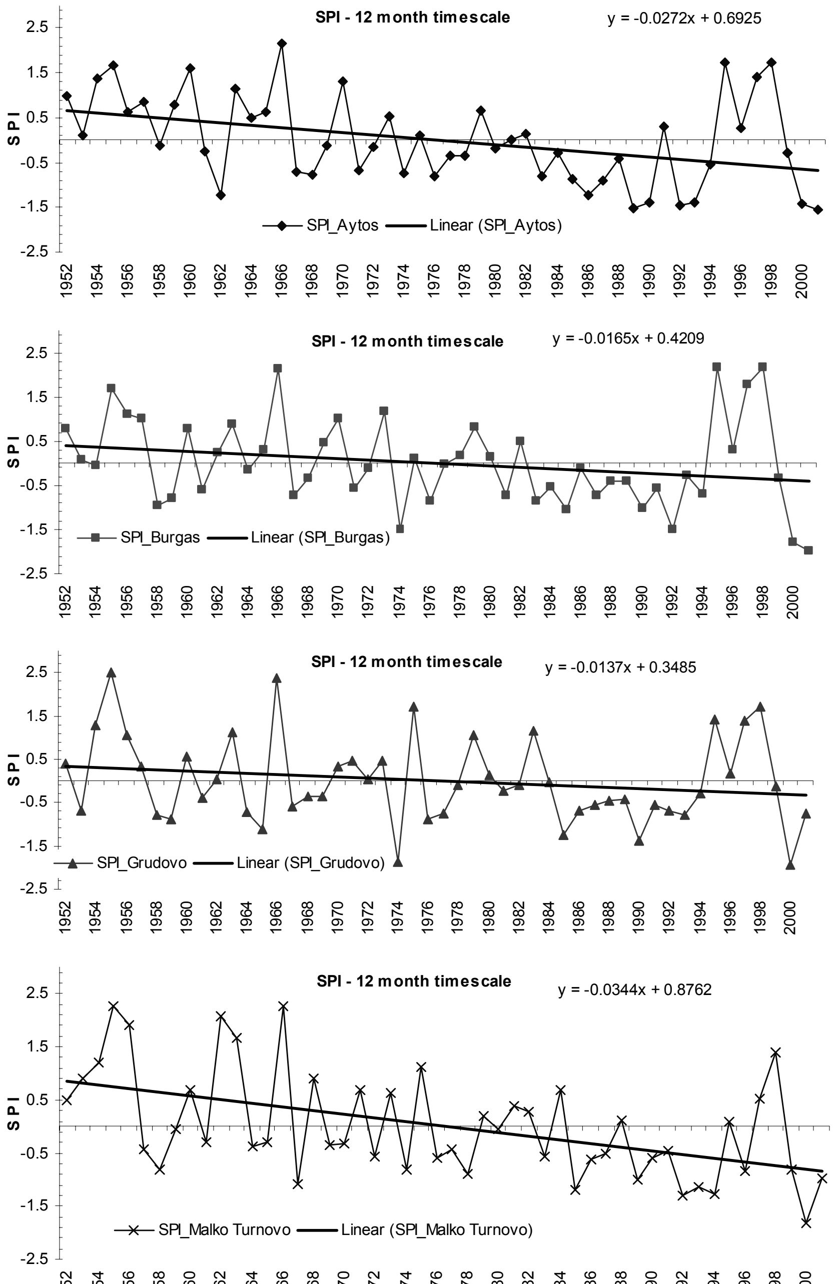

Fig. 4 Standardized Precipitation Index (SPI) for 12-month timescales and its trends at Aytos, Burgas, Grudovo and Malko Turnovo stations.

resources. Soil moisture conditions respond to precipitation anomalies on a relatively short time scale, while groundwater, streamflow, and reservoir storage reflect the longer-term precipitation anomalies. A drought event occurs at any time that the SPI is continuously negative and reaches an intensity where the SPI is –1.0 or less. The event ends when the SPI becomes positive. The SPI was calculated for 12-month periods. Figure 4 shows SPI calculated for several meteorological stations located in the region. The general shape of the trend patterns is similar for all the stations, but in the south there is a remarkable tendency of negative SPI values. In accordance with the SPI values, it was determined that the period from 1985 to 1994 was a drought in the study region (Fig. 4).

Study of long time series of hydrological data in the context of climate variability is very difficult task because of the influence of human activities. With regard to this, the hydrological reference book for the rivers of Bulgaria (Stoyanov, 1981) was referred to; it details a history of change in the environment (data on storage accumulation and release abstractions, diversions and inter-catchment transfers). The inquiries showed that for most streams in southeastern Bulgaria, disturbances to the natural regime of the streamflow increased after 1960. During the process a section of the time series was selected for which the streamflow of the Veleka River at Zvezdets and Gramatikovo was not disturbed; but in the catchments of the north exist relatively small disturbances, in view of that, the northern catchments were not included in this study.

The runoff regime in the studied catchments is characterized by considerable variability caused by precipitation fluctuations and other landscape elements. Figure 5 shows the anomalies of annual runoff, the linear trend and the 5-year moving average for the Veleka River at Gramatikovo. During the analysis it was found that before 1975 positive runoff anomalies prevailed. From 1976 to 1994 predominately negative runoff anomalies prevail, characterizing an exceptionally low water period; the lowest values are observed in 1993 (–6.4 $m^3 s^{-1}$). From 1995 to 2002 the streamflow fluctuations are rather sudden with an exceptional maximum in 1998 (12.7 $m^3 s^{-1}$). For the whole period 1952–2002, a negative trend is observed for the annual runoff (Fig. 5).

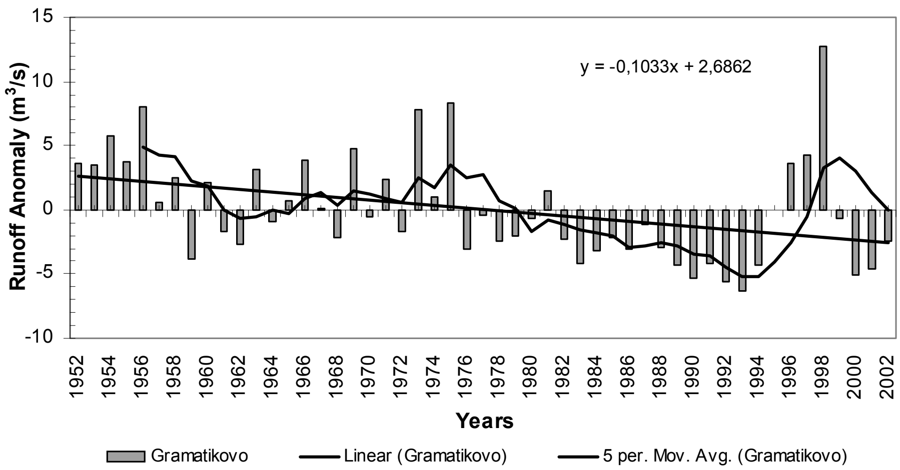

Fig. 5 Anomaly of annual runoff in the Veleka River at Gramatikovo.

CONCLUSION

The analysis of these long time series of river runoff, air temperature and precipitation allows us to draw some conclusions.

– The temperature increase is better expressed in the mountainous areas (Strandja Mountain) and weak in the Black Sea coastal zone.

- The precipitation decrease is more noticeable in the Strandja region compared to the rest of the study area.
- The Standardized Precipitation Index (SPI) for 12-month periods shows that a tendency for drought is evident in southeastern Bulgaria.
- For the whole period 1952–2002 a negative trend is observed for the annual runoff.
- There is a tendency of weak temperature increase and very noticeable rainfall and runoff decrease, the combination of which bring drought to the region

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