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RESEARCH ARTICLE

SPATIAL-TEMPORAL CHARACTERIZATION OF WATER QUALITY INDICATORS OF THE OPEN IRRIGATION CANAL 900 OF QARAOUN RESERVOIR, LEBANON

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ABSTRACT

Canal 900 is an open lined channel constructed to deliver 30 MCM per year of water from Qaraoun Lake at Litani River to irrigate agricultural lands of Bekaa Valley, Lebanon. From its inception, this canal has been plagued with setbacks due to excessive algal proliferation. This study aims at the assessment of the water quality indicators in 325 water samples of Canal 900 starting from the point of water outlet at Qaraoun reservoir till its end through the 2012 irrigation season. The results indicated elevated nutrient (nitrates and phosphates) concentrations that exceeded the recommendations to prevent aquatic ecosystems from developing eutrophication and algal proliferation all through the canal. This was associated with low DO levels and very high levels of BOD_5 and COD. In addition. significant spatial and temporal differences (at $p < 0.05$) in the mean values of most indicators were shown. The finding of this study should be considered in the development of a suitable water quality monitoring program and management strategy of both Qaraoun Lake and Canal 900 for a more safe use by farmers.

INTRODUCTION

Canal 900 is an open irrigation canal that gains its water from Qaraoun Lake as shown in Fig. 1., the largest fresh water man-made body in Lebanon. Qaraoun Lake was constructed in 1962 to harvest water from the most important river in the country, Litani River for hydropower generation, irrigation and dry season storage, Qaraoun Reservoir. Around 30 million m^3 of the reservoir's water is designed to irrigate around 7000 hectares of the farmland of Bekaa Valley through Canal 900 during the dry hot summer season (BAMAS, 2005a).

The prevailing climatic conditions in the Bekaa Valley are sub-continental with average annual precipitation varies between 600 and 800 mm. Temperature is strongly seasonal, with frequent frost periods in winter time that markedly limit vegetation development. A negative water balance (precipitation minus potential evapotranspiration), as a consequence of the high potential evapotranspiration, leads to severe water shortage and subsequent drought during the summer time from June through September, limiting thus agricultural production. Present estimates indicate that this fertile region consumes 1.5 times the annual ground and surface water replenishment (Karam and Karaa, 2000; Karam *et al*., 2003). This dire situation has led to a sharp drop in local water tables and deterioration of the quality of both surface and groundwater incurred from point and non-point sources of pollution in the shape of domestic, industrial wastewater and agricultural runoff (BAMAS, 2005b; LRBMS, 2011a,b). Under these conditions, several chemical and biological indicators exhibit high concentrations exceeding irrigation water quality standards, especially during the dry summer season (Slim *et al*., 2012; Korfali and Jurdi, 2011; MOE and UNDP, 2011; Abou-Hamdan *et. al*., 2014).

Although previous estimates of Canal 900 water quality generally indicated its suitability for irrigation, the canal has been subject to algae proliferation during summer causing water flow retardation, clogging of irrigation drippers, dreadful odor resulting in complaints from farmers and inhabitants in the surrounding area which necessitated sometimes the application of copper sulfate. As a result, many farmers have become unwilling to subscribe to the canal water deliveries. Accordingly, the canal generally operates at only around 30% of its capacity, serving only 1,900 hectares out of the originally planned 7,000 hectares of irrigated land. Alternatively, large number of farmers have turned to the use of groundwater.

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In view of the observed climate change conditions, heavy anthropogenic disturbances in the Litani Upper Basin and associated increasing demands for irrigation water, the current study was performed to characterize the spatial temporal variations of the water quality all through Canal 900 during the irrigation season of May to July, 2012. The study will contribute to the comprehensive assessment of the quality of the Canal's water from its origin at Qaraoun Lake till its end at Joub Jennine. It will promote our understanding of the ecological status of the Canal and contribute to the development of sustainable management strategies of important water resources of the country.

MATERIAL AND METHODS

Site Description

Canal 900 is an open lined channel of 18.5 km in length divided roughly into four equal segments. The irrigation water is pumped from the Qaroun Lake, flows through the Canal across the towns of Baaloul, Lala, Joub Jennine and Kamed Al Louze in West Bekaa (Fig1). The Canal has one main pumping station that pumps water from the reservoir, and three secondary pumping stations (K1, K2, and JJ) to deliver water to three reservoirs. Water is then conveyed downstream by gravity to the irrigation network. Five sampling sites extending between the Canal origin at Qaraoun Lake and its end at Kamed El Louz were selected for the study. The sites were distributed as one at the origin of Canal and four at all along the channel: Canal Head at 0.80 km from the origin, Pumping Station I (K1), Pumping Station II (K2), and Pumping Station III at Joub Jennine (JJ), the last three of which were situated at 5.72 km, 9.75 km and 17.25 km, respectively, of Canal Head (Fig.1).

Figure 1 Study sites at Qaraoun Reservoir and Canal 900 showing sampling locations (Reservoir, Canal Head, K 1, K 2, and Joub Jennine) during 2012 irrigation season

Sampling Method

Triplicate samples from all selected sites were on weekly basis collected at 50 cm below water surface during the irrigation season of 2012 (May to July), by Kemmerer Water Sampler (Annis Water Resources Institute, Grand Valley State University, USA, 2012). Samples were immediately transported on ice for analyses at the laboratories of Kherbet Kanafar Training and Extension Center of the Litani River Authority.

Climatic Conditions

Ambient weather data including solar radiation, air temperature, wind speed at 2m height, air temperature at dew point and relative humidity were recorded at hourly basis during 2012 by an automated weather station (METOS Compact, PESSL Instruments, Austria) at Kherbet Kanafar Training and Extension Center, Litani River Authority. The weather station was established within a standard meteorological park (40m N–S × 40m W–E). The weather station was automatically linked to a built-in data logger, which discharged at 10-min interval the registered meteorological data via standard wire communication into a computer situated in the weather monitoring unit of the Center.

Water Quality Indicators

A spectrum of physiochemical and biological indicators of water quality at selected sites were performed by both on site and laboratory tests at the laboratories of Kherbet Kanafar Training and Extension Center, Litani River Authority. pH by 370 pH Meter, JENWAY, E.U; dissolved oxygen (DO); and temperature by Gondo Ezodo PDO-408, Taiwan, were on site performed. Laboratory measurements of electrical conductivity (EC), total dissolved solids (TDS) and salinity by TRACER Pocket tester (LaMotte/ code 1749, USA); biological oxygen demand by B.O.D System 6 – FTC 90 – Refrigerated incubator (VELP- Scientifica, Spain); chemical oxygen demand (COD) by ECO6 Thermoreactor (VELP, Spain); and nutrient levels (phosphate, nitrate, nitrite, ammonia, sulfates) by colorimetery (La Motte, Model SMART2, USA) were all concurrently conducted. One-way analysis of variance (ANOVA) was performed using SPSS 19.0 software (SPSS, Statistical Package for the Social Sciences, University of Washington, Seattle WA, USA, 2010) at the significance level ($p < 0.05$).

RESULTS AND DISCUSSION

Climatic Conditions

Annual precipitation totaled 613 mm in the 2011-2012 growing year as recorded by the weather station of Kherbet Kanafar Training and Extension Centre. Almost 99% of the rain occurred between September and March, while only 1% of the rain fell in April-May with the growing season getting started. In addition, higher averages of air temperature than the annual records reaching its lowest at around 7^{o}C in February and highest at 30^{o}C in August were observed during spring and summer months. These prevailing weather conditions led to a pronounced drought that was recorded early in the season, thus pushing farmers anticipating the irrigation of their fields.

Spatial and Temporal Characterization of Water Quality Indicators

The mean values of water quality indicators assessed in studied sites of Canal 900 starting from its point of origin at Qaraoun Lake are presented in Table 1. In this table, it can be seen that TDS mean values at all studied sites ranging between 280.29 ± 34.99 mg/l and 362.64 ± 38.75 mg/l were within acceptable limits for human use and irrigation (FAO, 1994 and WHO, 2006). While DO values were around 6 mg/l, just above the critical level for aquatic life (5mg/l), BOD_5 ranged between 68.8 ± 58.62 mg/l and 84.2 ± 61.6 mg/l exceeding the limits of severely polluted water. This reflects the high organic contamination load of both the reservoir and canal waters (EPA, 1986). Similarly, the observed concentrations of COD ranging between 31.81 ± 11.31 mg/l and 61.96 ± 11.62 mg/l may also indicate high susceptibility to oxidation of the organic and inorganic materials present in these water bodies (UNESCO *et. al.*, 1996). The recorded moderate levels of NO_3 (20.36 ± 5.20 - 23.36 ± 4.09) and phosphates (0.34 ± 0.41 - 2.09 ± 4.87) were above the limits recommended by USEPA to prevent eutrophic conditions and algal growth in water bodies; below 10 mg/l for nitrates and below 0.1 mg/l for phosphates (USGS, 1996-1998). Comparable values were suggested by Dodds *et al*, (1998) for temperate steams (1500 µg TN/l and 75 µg TP/l) and by Camargo and Alonso (2006) (0.5-1.0 mg TN/l). The US Environmental Protection Agency (2002) has also recently published nutrient-criteria technical manuals taking into account two causal variable (TN and TP) and two response variables (algal biomass and water clarity).

As indicated in Table 1, spatial significant differences (at $p<0.05$) in the mean values of EC, TDS, salinity, nitrites, and sulfates were revealed by ANOVA statistical analysis. In addition, the t-test analysis between the mean values of the reservoir and those of the canal as whole indicated that while the levels of mineralization were higher in the canal, the reservoir recorded significantly higher means (*at* $p<0.05$) of phosphates and nitrites. Similarly, ANOVA analysis on the mean monthly values also revealed significant temporal variations at $p<0.05$ in most assessed indicators (Table 2). This spatial and temporal variability is in fact a consequence of the complexity of natural and anthropogenic inputs influencing the levels and cycling of nutrients and contaminants in surface water systems. Light and temperature conditions, dilution effects, biota assimilation (i.e. algae, macrophytes and phytoplankton), hydrodynamics as well as physic-chemical and biochemical processes, represent important influencing factors to be considered to underline the causes and significance of the observed spatial and temporal variations in this study.

The gradual increase in TDS, ammonia and NO_2 values in both the reservoir and canal indicated in Fig 2 and Fig 3a, 3b may be mainly attributed to higher water evaporation rates during summer as the air temperatures raise and possible decay of aquatic organisms, including phytoplankton, algae, plants inevitably causing increasing levels of these indicators towards the end of the season.

Noticeably, the overuse of fertilizers by farmers accompanied by runoffs may underline the relatively higher nitrates and phosphates levels recorded in the beginning of the study (Fig 3c and Fig 4). This increased availability of nutrients can disrupt the aquatic biological equilibrium that favored enhanced growth of phytoplankton and aquatic plant life and, consequently, led to an efficient uptake of nutrients as eutrophication process was setting in later in the season. Being widely present in natural waters at concentrations ranging from a few to several hundred milligrams per liter, the sulphate levels observed in Table 2 ranged around the average values of numerous water bodies in many countries, way below the USEPA contamination limits of 250 mg/l for drinking water (http://water.usgs.gov/ owq/topics.html). Further investigation is necessary to illustrate the dynamics and behavior of the different contaminants and nutrients in the reservoir and canal systems and understand the significance of their interactions and correlations. As apparent in in Table 2 the level of DO early in the season (May) was higher due to possibly low water temperatures. As eutrophication and organic materials were built up during the season, immense stress was placed on DO contents. The increasing trend in BOD_5 level towards the end of the season was a result of the high organic loads in Litani River and Qaraoun Lake waters attributed to the increased urbanization pressure, inappropriate agricultural practices and industrial activities and absence of effective management policies (Assaf and Saadeh, 2008; MoE and UNDP, 2011; Saadeh *et al*., 2012).

Table 1. Mean values ± SD of water quality indicators of Qaraoun Reservoir and Canal 900 during the irrigation season of 2012. a, b, c values with different superscripts are significantly different at $p<0.05$.

Indicator	Qaraoun Reservoir	Canal 900			
		Canal Head	K1	K2	Joub Jennine
EC *µS/cm*	384.14±48.21^{a}	477.36±30.56^{b}	469.14±33.98^{b}	458.79±35.97^{b}	451.64±29.24^{b}
TDS *mg/l*	280.29±34.99^{a}	362.64±38.75^{c}	353.86±35.40^{b,c}	342.57±36.22^{bc}	332.79±34.36^{b}
Sal *mg/l*	206.43±29.26^{a}	246±21.29^{b}	241.14±25.16^{b}	234.79±23.28^{b}	229.79±21.60^{b}
NO_2^- *mg/l*	0.79±0.33^{b}	0.63±0.18^{a,b}	0.67±0.18^{a,b}	0.64±0.17^{a,b}	0.61±0.14^{a}
NO_3^- *mg/l*	21.57±6.98	23.00±4.49	22.14±3.13	23.36±4.09	20.36±5.20
NH_3 *mg/l*	0.43±0.33	0.61±0.41	0.53±0.33	0.49±0.30	0.45±0.27
PO_4^{3-} *mg/l*	2.09±4.87	0.94±0.61	0.56±0.47	0.89±0.58	0.34±0.41
SO_4^{2-} *mg/l*	33.71±1.49^{b}	32.29±1.33^{a}	32.00±1.11^{a}	31.57±1.40^{a}	31.57±1.22^{a}
DO *mg/l*	6.48±1.55	6.31±1.49	6.40±1.51	6.29±1.47	6.19±1.44
BOD_5 *mg/l*	70.40±52.61	84.20±61.60	77.60±57.66	72.40±59.36	68.80±58.62
COD *mg/l*	61.96±11.62	43.58±18.09	37.83±16.54	33.97±12.92	31.81±11.31

Table 2 Mean monthly values of water quality indicators of Qaraoun Reservoir and Canal 900 during the irrigation season of 2012. a, b, c values with different superscripts are significantly different at $p<0.05$.

Indicator	Month	Qaraoun Reservoir	Canal 900			
			Canal Head	K1	K2	Joub Jennine
EC *µS/cm*	May	334.40±21.3^{a}	449.80±38.46^{a}	438.20±42.49^{a}	426.00±43.47^{a}	423.20±28.01^{a}
	June	382.75±5.91^{b}	493.50±7.77^{b}	483.00±4.76^{b}	470.25±10.01^{b}	455.00±6.63^{b}
	July	435.00±27.29^{c}	492.00±5.70^{b}	489.00±7.00^{b}	482.40±8.23^{b}	477.40±10.45^{b}
SO_4^{2-} *mg/l*	May	34.40±1.67^{b}	32.40±1.34	31.80±0.84^{a}	31.20±0.34^{a}	31.60±0.55^{a,b}
	June	34.50±0.58^{b}	33.00±1.41	33.25±0.96^{b}	33.00±1.41^{b}	32.75±1.26^{b}
	July	32.40±0.89^{a}	31.60±1.14	31.20±0.45^{a}	30.80±1.10^{a}	30.60±0.89^{a}
PO_4^{3-} *mg/l*	May	4.68±798	1.14±0.64	0.48±0.53	0.98±0.81	0.38±0.54
	June	0.53±0.48	0.70±0.73	0.43±0.51	0.70±0.53	0.13±0.25
	July	0.76±0.26	0.94±0.53	0.74±0.44	0.96±0.41	0.48±0.36
NO_2^- *mg/l*	May	0.47±0.05^{a}	0.47±0.04^{a}	0.50±0.07^{a}	0.50±0.02^{a}	0.50±0.07^{a}
	June	1.22±0.23^{c}	0.58±0.02^{b}	0.60±0.08^{b}	0.56±0.07^{a}	0.54±0.05^{a}
	July	0.77±0.06^{b}	0.84±0.08^{c}	0.88±0.03^{c}	0.84±0.09^{b}	0.77±0.08^{b}
NO_3^- *mg/l*	May	24.80±11.56	20.60±5.59^{a}	23.00±4.53	24.00±5.33	21.80±1.10^{b}
	June	20.75±1.71	26.75±3.86^{b}	23.50±1.73	24.75±3.40	25.25±5.38^{b}
	July	19.00±0.71	22.40±1.14^{a,b}	20.20±1.10	21.60±2.30	15.00±1.58^{a}
NH_3 *mg/l*	May	0.16±0.04^{a}	0.21±0.07^{a}	0.21±0.06^{a}	0.19±0.05^{a}	0.18±0.06^{a}
	June	0.29±0.21^{a}	0.50±0.16^{b}	0.45±0.13^{b}	0.46±0.10^{b}	0.43±0.14^{b}
	July	0.82±0.12^{b}	1.09±0.18^{c}	0.92±0.16^{c}	0.82±0.14^{c}	0.75±0.15^{c}
DO *mg/l*	May	8.12±0.54^{c}	7.90±0.64^{c}	7.94±0.21^{c}	7.74±0.13^{c}	7.52±0.24^{c}
	June	6.53±0.72^{b}	6.28±0.64^{b}	6.65±0.66^{b}	6.58±0.89^{b}	6.65±0.87^{b}
	July	4.80±0.49^{a}	4.74±0.54^{a}	4.66±0.44^{a}	4.60±0.35^{a}	4.50±0.32^{a}
Sal *mg/l*	May	176.20±12.60^{a}	225.40±12.54^{a}	215.60±13.59^{a}	211.40±13.22^{a}	208.20±11.19^{a}
	June	207.00±6.78^{b}	244.00±4.55^{b}	240.00±4.08^{b}	233.25±3.95^{b}	230.50±1.73^{b}
	July	236.20±18.39^{c}	268.20±12.24^{c}	267.60±12.95^{c}	259.40±11.46^{c}	250.80±15.94^{c}
TDS *mg/l*	May	245.80±18.54^{a}	320.80±32.66^{a}	316.80±31.78^{a}	306.60±33.31^{a}	297.60±25.12^{a}
	June	279.50±4.20^{b}	373.75±8.22^{b}	362.50±6.45^{b}	347.25±5.44^{b}	335.00±4.08^{b}
	July	315.40±24.38^{c}	395.60±9.61^{b}	384.00±10.22^{b}	374.80±13.97^{b}	366.20±15.67^{c}

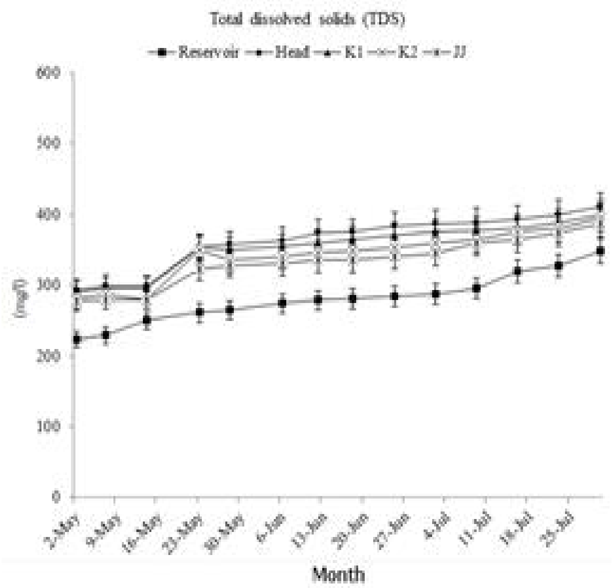

Figure 2 Temporal variation of total dissolved solids in Qaraoun Reservoir and along Canal 900 sampling locations during 2012 irrigation season. Data points are means of five readings ±SD.

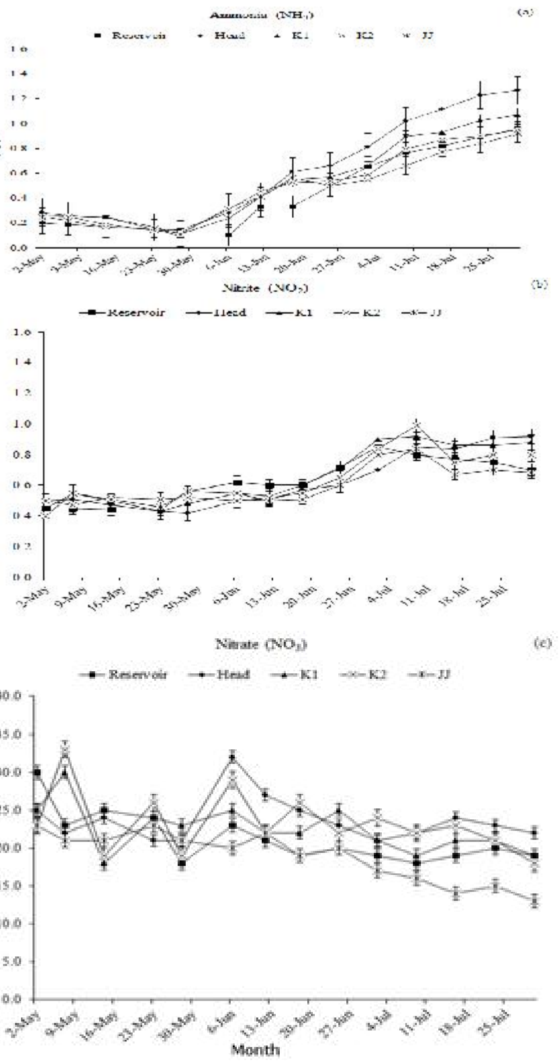

Figure 3 Temporal variation of ammonia (a), nitrite (b) and nitrate (c) during 2012 irrigation season. Data points are means of five readings ±SD.

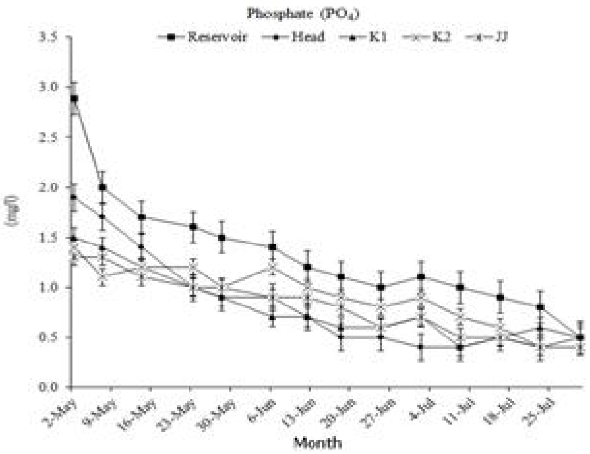

Figure 4 Temporal variation of phosphate in Qaraoun Reservoir and along Canal 900 sampling locations during 2012 irrigation season. Data points are means of five readings ±SD.

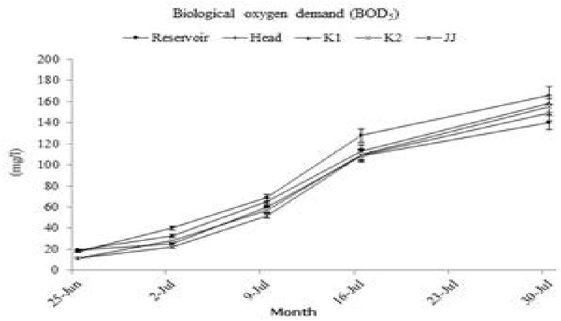

Figure 5 Temporal variation of biological oxygen demand in Qaraoun Reservoir and along Canal 900 sampling locations during 2012 irrigation season. Data points are means of five readings ±SD.

CONCLUSIONS

The findings of this study generally present a detailed knowledge of water quality indicators of Canal 900 necessary to develop appropriate management strategy of the water quality of Qaraoun Lake and Canal 900. The eutrophic conditions found in the reservoir and canal at the beginning of the irrigation season may be attributed to the high disposal of agrochemicals by way of the Litani River and Qaraoun Lake through the run-off during rainy season of winter. In fact, overuse of fertilizers by farmers at the beginning of the irrigation season is a common phenomenon that is assumed to ensure increased crop yield. The overuse of fertilizers, coupled with inefficient irrigation techniques, has become the major source of pollution of water resources in Bekaa Valley. The surface runoff is laden with nitrates as well as phosphates finding their way to the Litani River and Qaraoun reservoir and eventually Canal 900. Compounding this problem is the nature of soils, which is high in clay content, reducing the rate of infiltration, and increasing the rate of surface runoff. ANOVA statistical analyses indicate significant spatial (geophysical) and temporal (climate) features in water quality. This suggests the influence of combined processes starting from the agricultural run-off and wastewater from residential areas along with cycling and assimilation processes. Further studies to test the dynamics of nutrients and their effect on algal growth and biomass in both the reservoir and canal is needed to fully justify any management means. The data generated from this study will guide the continuing efforts to support a sound management for water ecosystems in the country.

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