



Climate Change and Sensitivity of Surface Water Resources in the Mekrou Sub-Watershed at the Yakrigourou Outlet (North Benin / West Africa)

Alain Ibikunle Ague^{1,*}, Cyr Gervais Etene², Somiyabalo Pilabina³, Ibouraima Yabi²

¹Multidisciplinary Doctoral School "Spaces, Cultures and Development", University of Abomey-Calavi, Godomey, Benin

²Pierre PAGNEY Laboratory on Climate, Water, Ecosystem and Development, Department of Geography and Land Management, University of Abomey-Calavi, Godomey, Benin

³Laboratory of Research on Spaces, Exchanges and Human Security (LaREESH), Department of Geography, University of Lome, Lome, Togo

Email address:

ibikalain@yahoo.fr (A. I. Ague)

*Corresponding author

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Abstract: The present work aims to contribute to a better understanding of the impacts of climate change on the availability of surface water resources in the Mékrou sub-basin at the Yakrigourou outlet in northern Benin. To achieve this objective, descriptive statistical methods were applied to hydro-climatological data. The historical data were taken from the Météo-Bénin database and from the General Directorate of Water in Benin. The simulation data are those of the HadGEM2-ES climate model under the RCP 4.5 and RCP 8.5 scenarios and then at horizons 50 (2041 to 2060) and 70 (2061 to 2080). The results show that the period from 1965 to 2018 is globally characterised by a strong irregularity of rainfall with a decreasing trend and a multiplication of dry years estimated at 54%. In the same way, the runoff decrease about 5.8 m³/s during the decade 2007-2016. Under the most pessimistic scenario (RCP8.5) and compared to the reference period (1971-1990), the HadGEM2-ES model predicts an increase in annual precipitation estimated at 8.29% by 2041-2060 and 13.83% by 2061-2080. As regards temperature, there could be an increase of 2.4°C by 2041-2060 and 3.7°C by 2061-2080. These climatic events affect the availability of surface water resources in the sub-basin.

Keywords: Climate Change, Sensitivity, Water Resources, Mekrou Sub-basin

1. Introduction

The climatic parameters that play a role in the availability of water resources are mainly precipitation, temperature and evaporative demand [1]. On a global scale, the scientific community is unanimous about the impact of variations in these parameters on surface water resources and its corollaries. Indeed, according to projections, increases in precipitation intensity and variability are expected to increase the risk of floods and droughts in several regions [2] and global warming of 2°C rather than 1.5°C would increase the risk of water scarcity in some regions [3].

In Africa, and mainly in West Africa, climate change is

manifested, among other things, by increased variability in rainfall, increases in maximum temperatures of 0.5 to 0.9°C and beyond +1°C for minimum temperatures [3].

In Benin, several authors including [4 - 12] have shown that the climatic physiognomy has undergone changes.

In Mekrou catchment, Vissin [13] showed that for a rainfall deficit of -12% during the sub-period 1973-1992 compared to 1955-1972, there is a 72% decrease in runoff. Similarly, in the same area, by using a set of three Climatics Models (MPI-REMO, DMI-HIRHAM5 and SMHI-RCA4), Obada and al., [14] indicates an increase in rainfall amounts over the period 2071 - 2100 for the RCP 4.5 and RCP 8.5 scenarios. Yabi [15] showed that the Sudanian zone of Benin, to which the Mekrou

basin belongs, is affected by the phenomenon of drought, which manifests itself in particular through significant rainfall deficits, late onset and early cessation of rainfall, and the appearance of dry sequences. These results show the complexity of climate change, whose impacts on water resources are obvious and can vary from one hydrological sub-unit to another. What then are the effects of the variation of climatic parameters on the surface water resources of the Mekrou sub-basin at the Yakrigourou outlet? The present

article aims to provide a solution to this question by characterising climate variability and its impact on surface water resources in the Mekrou sub-basin at Yakrigourou.

The Mekrou sub-basin at the Yakrigourou outlet is located in the northern part of Benin between 10° and 10°50' North latitude and between 1°31' and 2°10' East longitude (Figure 1). It covers an area of about 2643 km² and is spread over four communes, namely Kouandé (59%), Kérou (19%), Péhunco (21%) and Natitingou (2%).

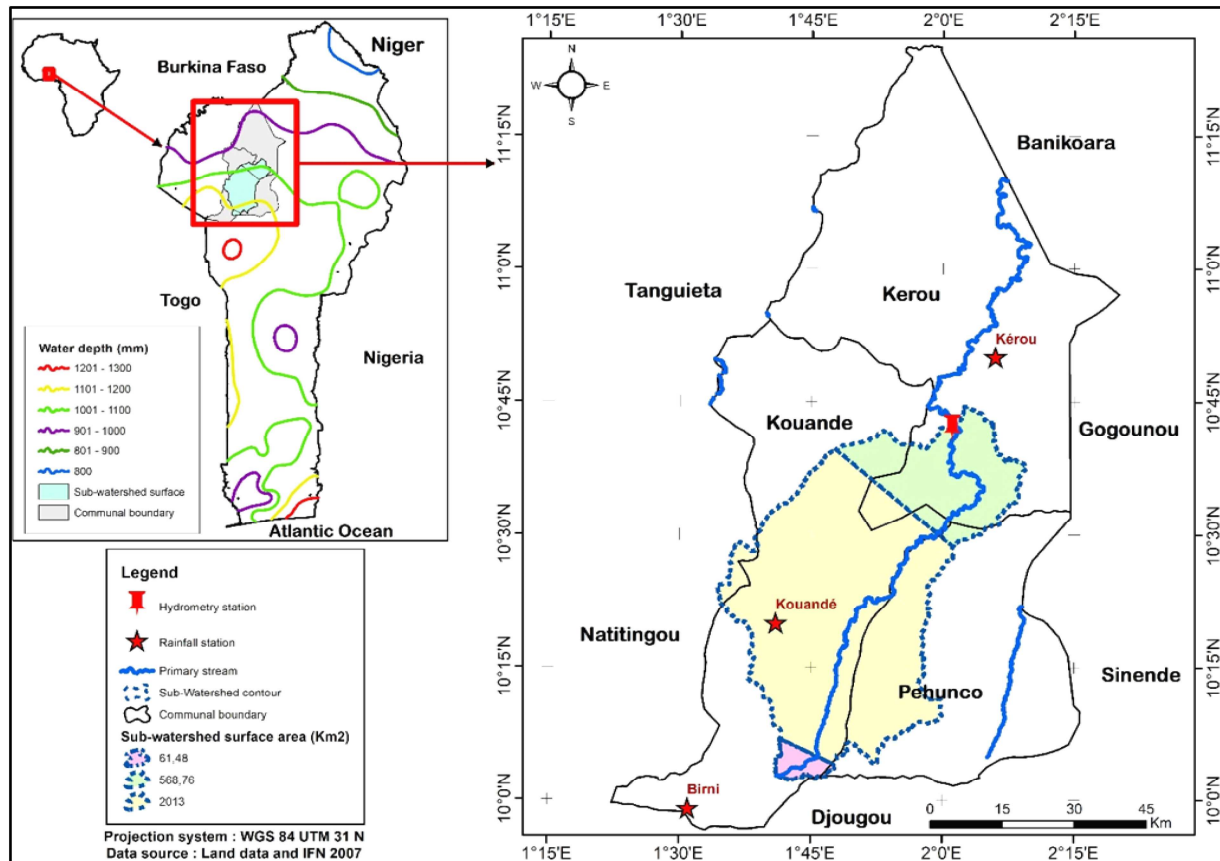


Figure 1. Study area.

2. Data and Methods

2.1. Data

The climatic data used in this study include monthly rainfall from three rainfall stations (Birni, Kouandé and Kérou) belonging to the study basin region, monthly temperatures and potential evapotranspiration from the synoptic station of Natitingou. They are collected from Benin Meteorology agency. Historical rainfall and temperature data cover globally the period 1965 to 2018. The future data concern the HadGEM2-ES (Hadley Global Environment Model 2 - Earth System) climate model under the RCP 4.5 and RCP 8.5 scenarios and at horizons 50 (2041 to 2060) and 70 (2061 to 2080). They come from the archives gathered under the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project 5 (CMIP5) [16]. The

hydrometric data used are obtained from the hydrology department of the Directorate General of Water in Benin. These are daily flows from the Yakrigourou station over the period 2007 to 2019.

2.2. Methods

The rainfall average on the sub-basin has been calculated using the Thiessen method written as (1) because the application is easy [17]. La figure 1 présente aussi les aires du bassin délimitée par le polygone de Thiessen. Figure 1 also shows the areas of the basin delimited by the Thiessen polygon.

$$\bar{P} = \sum_i^n \frac{S_i P_i}{S} \quad (1)$$

\bar{P} : rainfall average in the sub-basin;

S_i : Sub basin area délimitated by Thiessen polygon for the station « i »;

P_i : Annual rainfall for the station « i »;

P_i : Total surface of the sub-basin.

The Standardised Index (SI) has been used for the determination of dry and wet years for precipitation and cool and warm years for temperature. This index is used by several authors including [18] and is written by the following formula (2):

$$SI_a = \frac{X_a - X_m}{\sigma_x} \quad (2)$$

This formula was applied to the rainfall, temperature and flow data.

When considering rainfall data, X_i is the annual rainfall average for the year «a» in the sub-basin; X_m and σ_x , are respectively the mean and standard deviation of the annual rainfall in the sub-basin.

To analyse the Standardised Precipitation Index, we considered the severity thresholds established by the standard deviation method presented in Table 1 [19].

Table 1. Classification of drought indicators.

SPI values	Classes
More than 2.0	Extremely wet
1,5 à 1,99	Severely wet
1,0 à 1,49	Moderately wet
-0,99 à 0,99	Near normal
-1,0 à -1,49	Moderately dry
-1,5 à -1,99	Severely dry
Less than -2,0	Extremely dry

Climate change is analysed using the methods of [20] and [21] also used by [16]. They meet the following formulas (3):

$$D_{horiz} = \bar{P}_{horiz} - \bar{P}_{ref} \text{ and } E_{horiz} = \frac{\bar{P}_{horiz} - \bar{P}_{ref}}{\bar{P}_{ref}} * 100 \quad (3)$$

where D is the relative difference, \bar{P}_{horiz} = average horizon 50 (2041-2060) or horizon 70 (2061-2080), \bar{P}_{ref} = average for the reference period (1971-1990) and E = % difference corresponds to the relative increase or decrease in average precipitation or temperature (horizon 2050 or 2070) compared to the average of the reference period (1971-1990).

The availability of water resources is analysed by the climate balance (4) also used by [13]:

$$Bc = P - ETP \quad (4)$$

Where Bc is the climatic balance in mm, P is the rainfall in mm and ETP means the potential evapotranspiration in mm.

If $Bc > 0$, the balance is surplus; if $Bc < 0$, the balance is deficit and if $Bc = 0$ the balance is balanced.

3. Results

3.1. Current Hydro-climatic Trends in Mekrou Sub-basin at Yakrigourou

3.1.1. Rainfall and Thermal Variability in Mekrou Sub-basin at Yakrigourou

Figures 2 and 3 presented respectively the variation of the standardised rainfall index and the temperature in the sub-

basin of the Mekrou at Yakrigourou.

The analysis of figure 2 shows that the period (1965 - 2018) is globally characterised by a strong irregularity of rainfall with a downward trend estimated at about 14.4%. There has also a multiplication of the number of dry years, estimated at 54% and covering the years from 1980 to 1990. The years 1983 and 1992 show a severe drought with an index of 1.77 and 1.71 respectively. At the same time, figure 3 shows that 56% of years including the period from 1998 to 2012 were warm. By the moving average, we observe an increasing trend of the average temperature, estimated at 0.4°C in the sub-basin.

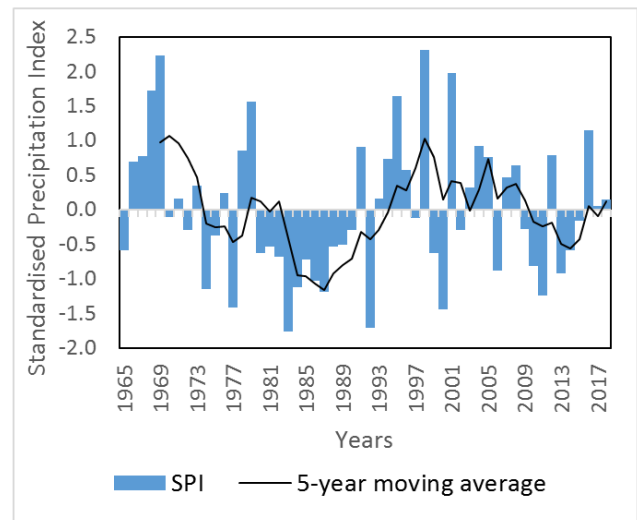


Figure 2. Evolution in the standardised precipitation index.

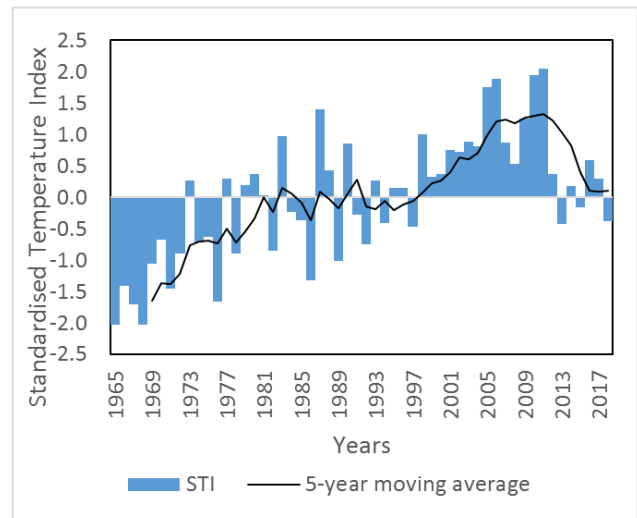


Figure 3. Evolution in the standardised temperature index.

3.1.2. Flow Variability in Mekrou Sub-basin at Yakrigourou

Figure 4 shows the inter-annual variability of the Mekrou flow in Yakrigourou. From the analysis of this figure, it can be seen that the evolution of the indices shows an important variation of the flows in the sub-basin. The moving average has allowed for a better visualization of the variation of flows and clearly shows the decade from 2007 to 2016 as a dry

period with a decrease in flow by $5.8 \text{ m}^3/\text{s}$. We also note that the period from 2017 to 2019 is wet.

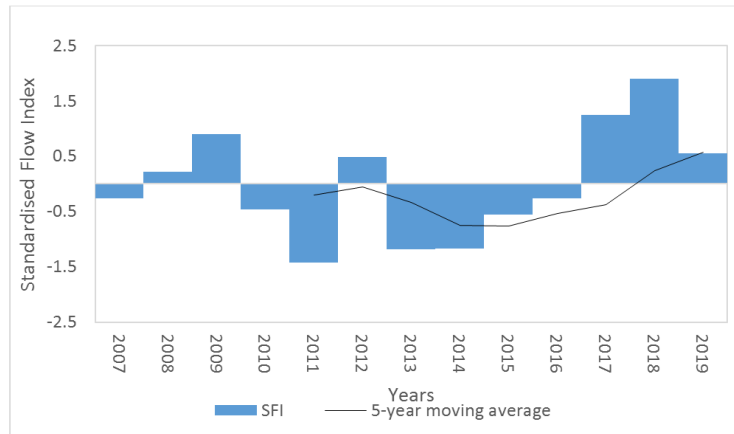


Figure 4. Evolution of the standardised flow index between 2007 and 2019 at Yakrigourou.

3.2. Climate Projections in Mekrou Sub-basin at Yakrigourou

Table 2 presented the variation of annual rainfall mean for horizon (2041-2060) and the horizon (2061-2080) compared to the reference period (1971-1990) under the RCP 4.5 and RCP 8.5 scenarios.

Table 2. Projected change in annual average precipitation.

	RCP 4.5 Scenario		RCP 8.5 Scenario	
	Average (mm)	Variation (%)	Average (mm)	Variation (%)
Horizon 50 (2041 - 2060)	1212.67	6.62	1231.67	8.29
Horizon 70 (2061 - 2080)	1241.33	9.14	1294.67	13.83

The analysis of this table shows that the HadGEM2-ES model predicts an increase of annual rainfall for all scenarios. According to the RCP 4.5 scenario, this increase is estimated at 6.62% between the periods 1971-1990 and 2041-2060 and 8.29% between 1971-1990 and 2061-2080. When considering the most pessimistic scenario (RCP 8.5), those percentages rise respectively to 8.29% and 13.83%. On a

monthly scale (Figure 5), the month of April, which currently marks the start of the rainy season, will experience a decrease in rainfall, whatever the scenario and the time horizon. This decrease is estimated at -14.5% under RCP 4.5 and -8.5% under RCP 8.5 at horizon 50, then at -10.2% under RCP 4.5 and -9.2% under RCP 8.5 at horizon 70. On the other hand, the month of March, currently in the dry season, will experience an increase of rainfall. The increase is more significant in the rainy months, particularly August and September, and could lead to flooding in the sub-basin.

Considering the temperature, we note that the model predicts an increase by 1.6°C under RCP 4.5 and 2.4°C under RCP 8.5 on the horizon 2041-2060 and also by 2.2°C under RCP 4.5 and 3.7°C under RCP 8.5 on the horizon 2061-2080. In addition, the increase of temperatures is observed from January to December and the values under the most pessimistic scenario (RCP8.5) are clearly higher than those obtained under the RCP4.5 scenario as shown in figure 6. This situation will increase the evaporative demand from the atmosphere and could worsen the surface water shortage.

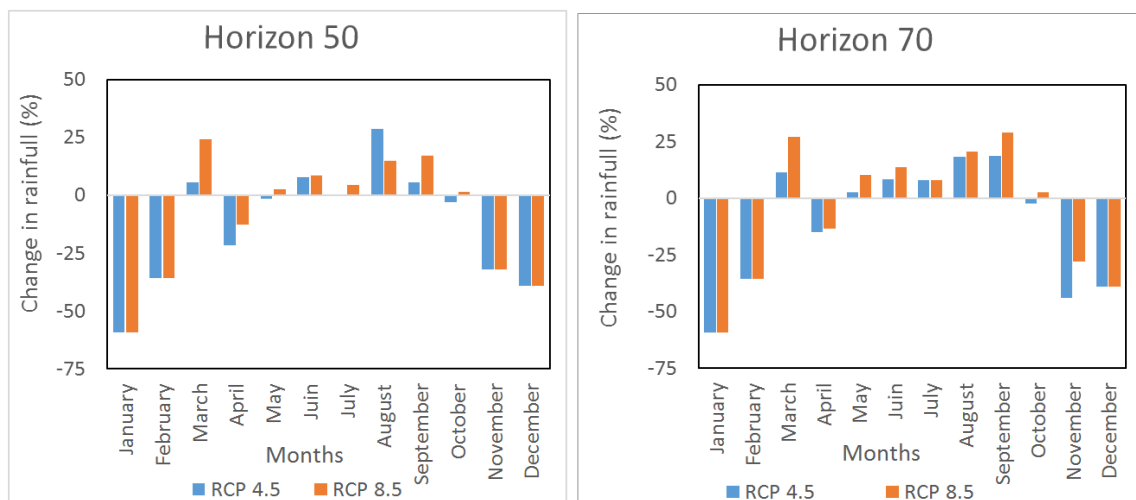


Figure 5. Change of projected monthly rainfall.

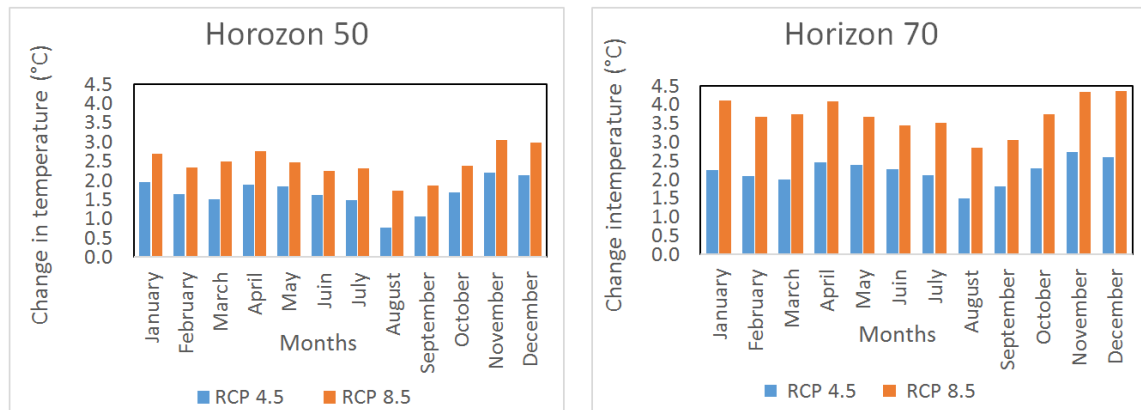


Figure 6. Change in projected monthly temperatures.

3.3. Potential Impacts of Climate Change on Water Resources in the Sub-basin

Figure 7 shows that the climate balance is negative from October to May and positive from June to September. The average monthly temperatures vary from 24.8°C in August, which coincides with the strongest climatic balance of about +171.92 mm, to 30.2°C in March, which

has the most deficient climatic balance estimated at about -134.36 mm. In addition, the interannual climatic balance is globally negative and estimated on average at -292.92 mm. These results show the reinforcement of the evaporating power, particularly from October to May, which corresponds to a climatic pressure on the water resources in general and surface water in the catchment area in particular.

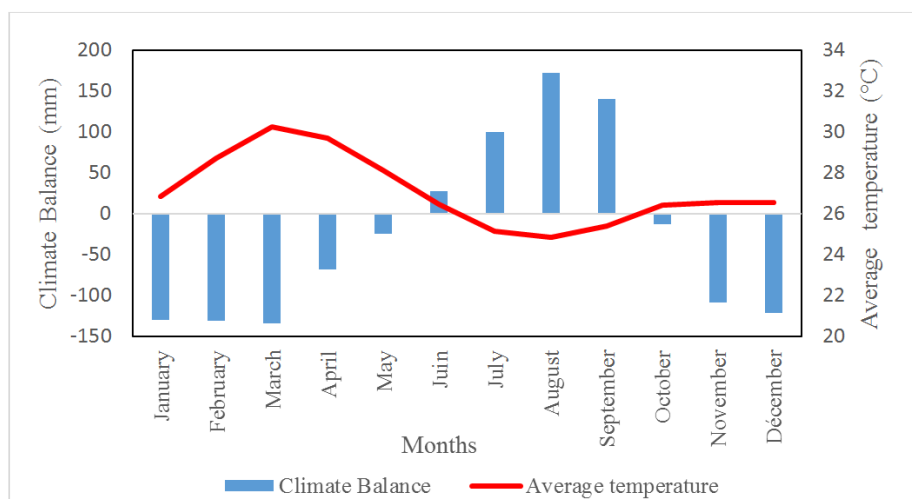


Figure 7. Average temperature and monthly climate balance.

4. Discussion

The decreasing rainfall trend is consistent with studies carried out in the Mekrou catchment by [13] and in border regions such as Burkina Faso [22, 23] and on the Kara basin in Togo [18, 24]. The author [13] also noted a decrease in the flow of the Mekrou and the increase in dry years corroborating the results obtained by [15] in the Sudanian zone of Benin. Moreover, the temperature increase is in line with the results of [25] in West Africa and confirms once again the problem of global warming with its corollaries such as the increase in the evaporative capacity of the area and the pressure on surface water resources [18, 21, 26]. In the Oum Erbia water basin in Morocco, [27] also observed an increase

in its average temperature. This situation, which could worsen in the future at the level of the Mekrou sub-basin at the outlet of Yakrigourou, will limit the availability of surface water resources and in turn impact the human population and agricultural activities as notified by [18] in 2019 in the Kara catchment.

5. Conclusion

The present study revealed that the Mékrou sub-basin at the Yakrigourou outlet, between the period 1965 - 2018 is characterized by a strong irregularity of rainfall with a downward trend estimated at about 14.4% and then an increase in dry years estimated at 54%. Temperature, like in West Africa, has increased by 0.4°C, while runoff has tended

to decrease over the decade from 2007 to 2016. On an annual scale and according to the RCP 4.5 scenario, rainfall could increase by 6.62% at the horizon 2041-2060 and by 8.29% at the horizon 2061-2080. On the most pessimistic scenario (RCP 8.5), those percentages rise respectively to 8.29% and 13.83%. With regard to temperature, an increase is also expected whatever is the scenario and the period. The monthly climate balance is negative from October to May and positive from June to September. The results showed an increase of evaporative capacity, which corresponds to climatic pressure on surface water resources.

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