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Climatic instability and low-flow regimes

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ABSTRACT: The low-flow regimes of the Acheloo's river at the Mesochora catchment outfall in Central Greece were analyzed under climatic instability conditions. The climatic instability pattern was simulated through a set of hypothetical and monthly GISS (Goddard Institute for Space Studies) scenarios of temperature increases, coupled with precipitation changes. The daily flow of the catchment, which is dominated by spring snowmelt runoff, was simulated by the coupling of the snowmelt and soil moisture accounting models of the US National Weather Service River Forecast System. A low-flow day was defined as a day during which the streamflow did not reach the quarter of the long-term mean daily streamflow. In this case the low-flow components (occurrences, duration, magnitude, etc) were determined. Both representations of climatic instability resulted in more numerous and longer low-flow episodes, as well as smaller mean values of minimum streamflows. Also, all climate cases posted larger low-flow deficits as the precipitation increased. These results could possibly further jeopardize the river water quality, the reliability of the storages and dams, as well the water supply from local groundwater sources.

INTRODUCTION

Knowledge concerning low-flow regimes and droughts (extended low-flow periods lasting from months to years) is perhaps the most important aspect in the planning of water resource systems, the allocation of available streamflows among a variety of competing uses and finally the mankind survival and welfare. Although the atmospheric and ocean circulation failures (anomalies) associated with greenhouse and anthropogenic operations are mainly responsible for water shortage occurrences (Nicholls 1989, Richey *et al.* 1989, Trenberth *et al.* 1988, Dickinson & Henderson-Sellers 1988, Lean & Warrilow 1989, Shukla *et al.* 1990), none of general circulation models (GCMs) or any downscaling scheme thereof, or even the most promising SVAT (Soil - Vegetation - Atmoshere Transfer) models (BAHC 1993) can yet simulate and predict accurately such episodic events at any spatial and temporal scale.

Thus, for catchment scale areas, we resort to hydrological assessment of such events by coupling the GCM outputs (temperature, precipitation, etc) and conceptual hydrological models. In this sense, the present day surface climatological data must be adjusted to account for climate instability scenarios.

This paper is concerned with the response of low-flow parameters of a stream (number of episodes, duration, magnitude, etc) to hypothetical and GISS (Goddard Institute for Space Studies) modelled climate instabilities. A thorough understanding of low-flow components under climatic disturbances is also necessitated for devising valid methods of performing regional low-flow frequency analysis under altered climates.

EXPERIMENTAL DESIGN

The Acheloos river at the Mesochora catchment outfall in Central Greece was selected for an analysis of the low-flow regimes to climatic instability, due to its partial diversion for irrigation and hydropower purposes. The part of the river which drains the Mesochora catchment flows freely (no upstream diversions or flow regulations). The network of meteorological stations installed in and around the

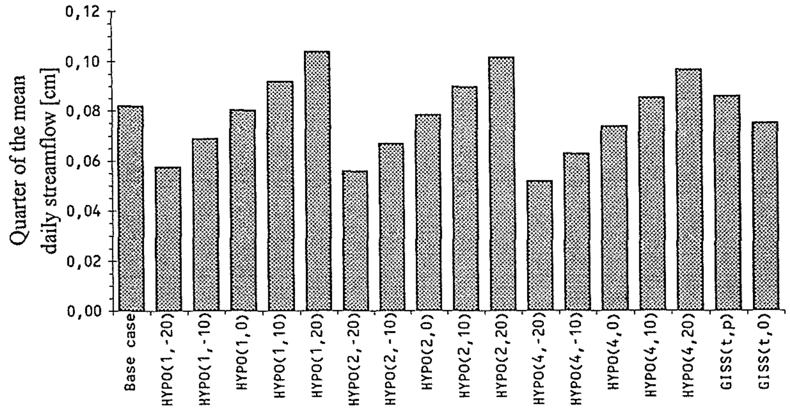

Figure 1 Low-flow threshold of Acheloo's river at Mesochora catchment outfall for the HYPO, GISS and base case climate scenarios.

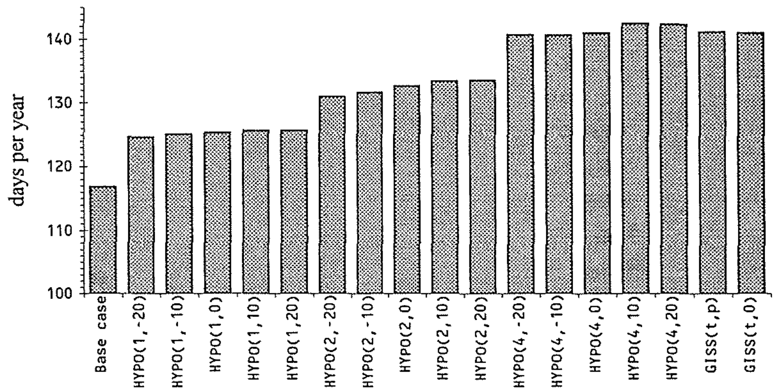

Figure 2 Mean number of low-flow days per year of Acheloo's river at Mesochora catchment outfall for the HYPO, GISS and base case climate scenarios.

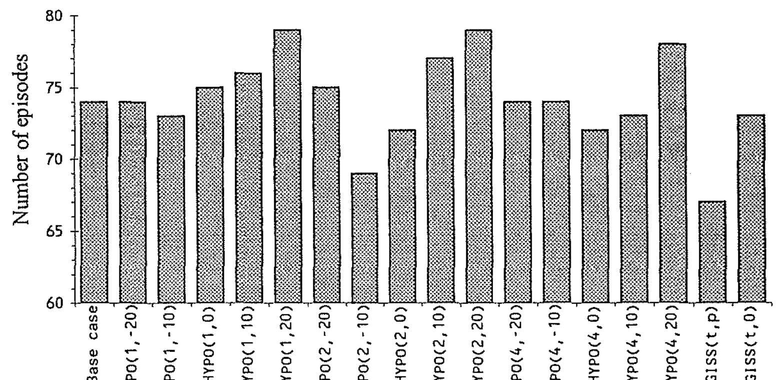

Figure 3 Number of low-flow episodes of Acheloo's river at Mesochora catchment outfall for the HYPO, GISS and base case climate scenarios.

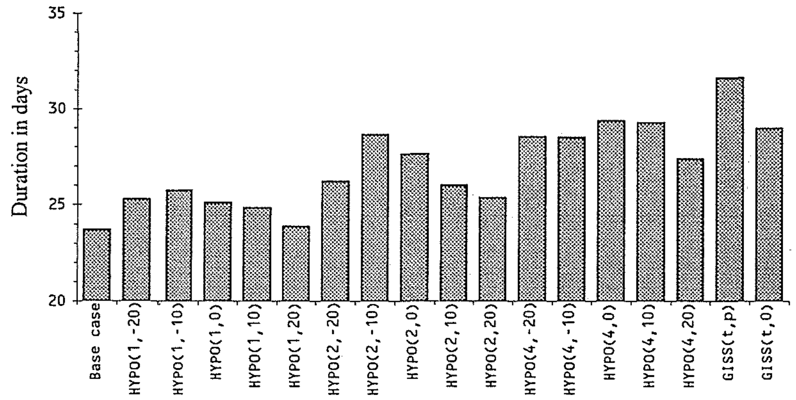

Figure 4 Mean low-flow duration of Acheloo's river at Mesochora catchment outfall for the HYPO, GISS and base case climate scenarios.

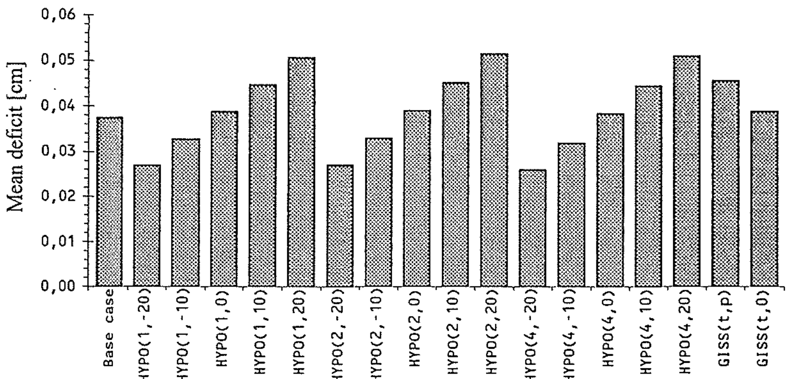

Figure 5 Mean low-flow deficit of Acheloo's river at Mesochora catchment outfall for the HYPO, GISS and base case climate scenarios.

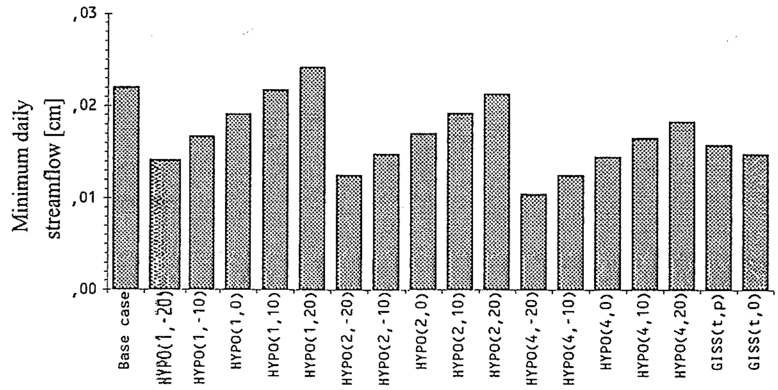

Figure 6 Mean minimum low-flow of Acheloo's river at Mesochora catchment outfall for the HYPO, GISS and base case climate scenarios.

catchment is relatively dense, but 3.5% of daily precipitation values and 15.5% of daily min-and-max temperature values were missing for the 15-year period used in this study (1972-1986). The climate in the Mesochora catchment is elevation-dependent, its mean elevation is 1390m, and its hydrology is controlled by snowfall and snowmelt.

The catchment area is 632.8 km^2, its annual precipitation is 189.8 cm and its runoff is 117.0 cm. A more detailed description of the catchment has been presented by Panagoulia (1992a, 1992b, 1991a).

The approach of conceptual hydrological simulation was adopted in this study to reproduce the outflow of a medium-sized catchment. Two hydrological models were used: the snow accumulation and ablation model of Anderson (1973) and the soil moisture accounting model of Burnash *et al.*, (1973). The snowmelt model describes the change in storage of water and heat in the snowpack, based on six-hourly precipitation and temperature data. The runoff model accounts for the flux of soil moisture between five conceptual storage zones.The runoff model accepts as inputs the snowmelt model output "daily rain plus melt" and long-term average monthly potential evapotranspiration, which in this study was computed according the Penman equation (Veihmeyer 1964) and disaggregated by the model into daily increments.

Since precipitation and temperature are strongly dependent on elevation, the snowmelt model was implemented using an elevation band method. The study catchment was divided into three elevation zones (about 30% of total area for each of the upper and middle zones and 40% for the lower zone). Eleven precipitation stations and three temperature stations were used in the process. Because the daily precipitation records were incomplete, the zone areal precipitation was assessed through the Thiessen method for all the combinations of zone stations which were giving out data for that particular day. The estimated zone areal precipitation was corrected for the median zone elevation. The above mentioned combination technique was also used to estimate the zone areal daily max-and-min temperature (Panagoulia 1991b, 1993). The study catchment mean areal precipitation (MAP) was formed as the average of the snowmelt output over the elevation zones (the weighting was proportional to the elevation zone areas). The MAP was then used as input to soil moisture accounting model.

The models were manually calibrated (Peck 1976) and their final parameter estimates (over the 15-year period) were obtained through a trial-and-error approach, which was carried out concurrently for both models. The typical monthly simulation errors (monthly differences between simulated and observed streamflows), expressed as a percentage of observed flows, were of the order of 10-15% (in August and September they reached 23%). The results of error analysis of daily flows, as well as the three day volume error analysis have showed a good representation of the observed daily streamflow (Panagoulia 1992a).

The historical input data were adjusted to reflect the climatic instability simulated by:

(a) fifteen hypothetical scenarios denoted as HYPO (ΔT,ΔP), where ΔT is temperature increase by 1, 2, 4 °C and ΔP is precipitation change by 0, ±10, ±20 % (Panagoulia 1991a), and

(b) two GISS-predicted scenarios (with both monthly precipitation and temperature changes GISS(t,p), and with monthly temperature changes alone GISS(t,0)) (Panagoulia 1992b).

LOW-FLOW REGIMES

A low-flow day was defined as a day during which the streamflow did not reach the quarter of the long-term mean daily streamflow (Shaw 1984). In this case and according to the runs theory (Yevjevich 1967, Dracup *et al.* 1980a,b, Gellens 1991) the low-flow parameters were determined by computing:

(i) the mean number of low-flow days per year,
(ii) the number of low-flow episodes in the period under reference,
(iii) the mean duration,
(iv) the mean low-flow deficit under threshold and
(v) the mean minimum flow.

The responses of the selected threshold and the five aforesaid parameters simulated for 15 years and 18 alternative climates are plotted in Figs 1-6 and a brief interpretation of these figures follows.

Low-flow threshold

The threshold (the quarter of the long-term mean daily streamflow) for all climates is presented in Fig. 1. This reflected a progressive augmentation with precipitation increase for all HYPO and GISS climate cases, but compared with the base case (historical climate conditions) it was declining as the precipitation reduced.

Days per year

The mean number of low-flow days per year (Fig. 2) which is significantly greater than that of base case for both HYPO and GISS cases, reflected also a progressive rising as the temperature increased.

Episodes

Figure 3 shows more numerous low-flow episodes with precipitation increase and a rather erratic behaviour with precipitation reduction for the HYPO cases. As regards the GISS climates, these yielded fewer low-flow occurrences as the precipitation increased.

Duration

Figure 4 reflects longer low-flow days and episodic events for both HYPO and GISS climates. The HYPO (4,0) scenario produced the longest episodes among the HYPO cases, while the GISS(t,p) yielded the longest ones between HYPO and GISS scenarios.

Deficit

Both HYPO and GISS climate cases produced increased low-flow deficits with precipitation rising (Fig. 5). The HYPO(t,0), HYPO(t,10) and HYPO(t,20) cases, as well as the GISS scenarios posted larger deficits than those of the base case.

Minimum flow

The mean minimum daily flow is smaller than that of the base case for both HYPO and GISS climates (Fig. 6), but it increases progressively with precipitation rising.

CONCLUSIONS

Recognizing the different methods by which the climatic instability was simulated (HYPO and GISS monthly representations) the main conclusions from the present study are as follows:

- The HYPO and the GISS climate instability scenarios displayed similar patterns of the low-flow parameter behaviour.
- All the scenarios resulted in more numerous and longer low-flow episodes, as well as smaller mean values of minimum streamflows. Also, all the climate cases posted larger low-flow deficits as the precipitation increased. These results associated with the summer and autumn runoff reduction (Panagoulia 1993) could possibly further jeopardize the river water quality, the reliability of the storages and dams, as well as the water supply from local groundwater sources.
- Significant differences in numerical results among climate cases were noticed due to the wide range of the climate variable instability.

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