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CATCHMENT SOIL MOISTURE SENSITIVITIES TO CLIMATE CHANGES ASSESSED FROM INCOMPLETE CLIMATOLOGICAL DATA

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1. INTRODUCTION

Present general circulation models (GCMs) [5], [6] can only grossly simulate the observed large-scale soil moisture, as well as its long-term seasonal variability. Much more, they cannot at all simulate and predict accurately observed regional or local soil moisture that is needed for making detailed assessments and predictions of agricultural, ecological, hydrological, and societal impacts. Thus, for catchment scale areas, the coupling of GCM output (temperature, precipitation, etc) and hydrological models, including soil moisture components, can only face the above cited problem. In this sense, the present day surface climatological data must be adjusted to account for climate change scenarios.

This paper deals with the long-term soil moisture responses of a medium-sized mountainous catchment to hypothetical and GISS (Goddard Institute for Space Studies) modelled climate changes. The climatological data used in the study include incomplete point values of daily precipitation and minimum/maximum temperature. In order to preserve the physical nature of climatic information and thus avoid the errors caused by the interpolation techniques [3], [4],[16], we would rather not estimate the unavailable values, but integrate instead the existing ones for areal variation and change with elevation.

2. EXPERIMENTAL DESIGN

We selected the Mesochora catchment of the Acheloos river in Central Greece for an analysis of the soil moisture responses to global climate changes [13], due to the partial diversion of the river for irrigation and hydropower purposes.The network of meteorological stations installed in and around the 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 [9], [10], [11].

The methodology of conceptual hydrological simulation was adopted in this study in order to achieve detailed representation of a medium-sized catchment. Two hydrological models were used: the snow accumulation and ablation model of Anderson [1] and the soil moisture accounting model of Burnash et al, [2]. 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 assumes the flux of soil moisture between five conceptual storages 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 [15].

For better performance of the snowmelt model, the 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 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 [9]. 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 calibration period was 15 years for both models. The models were manually calibrated [14] and their final parameter estimates 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 historical input data were adjusted to reflect the altered climates simulated by

(a) fifteen hypothetical scenarios denoted as HYPO(ΔT,ΔP), where ΔT is temperature increase by 1, 2, 4 ^{o}C and ΔP is precipitation change by 0, ±10, ±20 %, 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)) [10].

Thus, all the input precipitation time series were multiplied for the HYPO cases by a uniform factor and the GISS cases by the monthly precipitation ratio (the ratio of monthly precipitation for CO_2-doubling to the control run) applied for the centre of the catchment (39^{o} 34′N latitude and 21^{o} 19′E longitude). The HYPO temperature increases were applied uniformly to all daily values of the historical input series, while the GISS-predicted monthly temperature differences between the CO_2-doubling and control run were added to the input historical data as well.

For the HYPO cases the potential evapotranspiration (*PET*) was computed with the indicated temperature increases, which were applied uniformly to the historical monthly temperature data. For the GISS cases, the *PET* was also computed for the monthly temperature data for the

CO_2-doubling and the control run. The monthly differences in *PET* were computed and these differences were then added to the historical *PET* data.The other variables (wind speed, humidity, solar radiation, etc) remained unaltered in the Penman equation for both HYPO and GISS cases.

3. SOIL MOISTURE RESPONSES

This paper restricts the analysis to three variables: monthly mean upper zone free water,monthly mean lower zone free primary water and monthly mean lower zone free supplemental water over the catchment. The monthly mean snow water equivalent, runoff, evapotranspiration and two zone (upper and lower) tension water over the catchment are described in other studies [7], [8], [10], [11]. The soil moisture scenarios of the above three variables are plotted in Figs 1-3 and a brief interpretation of these figures follows:

3.1 Upper zone free water

The free water contents in all three zones of the model are strongly and erratically influenced by HYPO and GISS scenarios, as well as from month to month under the same scenario. Notwithstanding that, the free moisture content of the upper zone (Fig 1) posted larger fluctuations than those of the lower zones (Figs 2,3). Indeed, it peaked in January for the drier HYPO climate scenarios and in December for the rest HYPO, GISS and the base case, while during the summer dry period (July-October), the upper zone free water went down for all HYPO and GISS cases.

3.2 Lower zone primary free water

The free moisture content of the lower primary zone (Fig 2) supplies the baseflow with larger amounts than those of lower supplement zone. It peaked in March for 13 of the 15 HYPO and GISS cases, while that of the base case reached its maximum in May. The other two scenarios HYPO(1,-20) and HYPO(1,-10) caused the primary free moisture content to come to a maximum in April. For all HYPO and GISS scenarios the primary free moisture was minimized in October.

3.3 Lower zone supplemental free water

For 12 of the 15 HYPO scenarios and GISS(t,0) the supplemental moisture content (Fig 3) peaked in March, while for the GISS(t,p), HYPO(2,-10), HYPO(4,-20) and HYPO(4,-10) the peak shifted to February. The GISS(t,0) case appeared shifted earlier by one month from the peak month (April) for the base case. This content is minimized in August for HYPO and July-September period for GISS climate cases.

4. CONCLUSIONS

The main conclusions from the present study are as follows:

* The HYPO and the GISS climate scenarios displayed similar profiles of monthly distributions of the catchment soil moisture storages.Both cases showed that increased precipitation

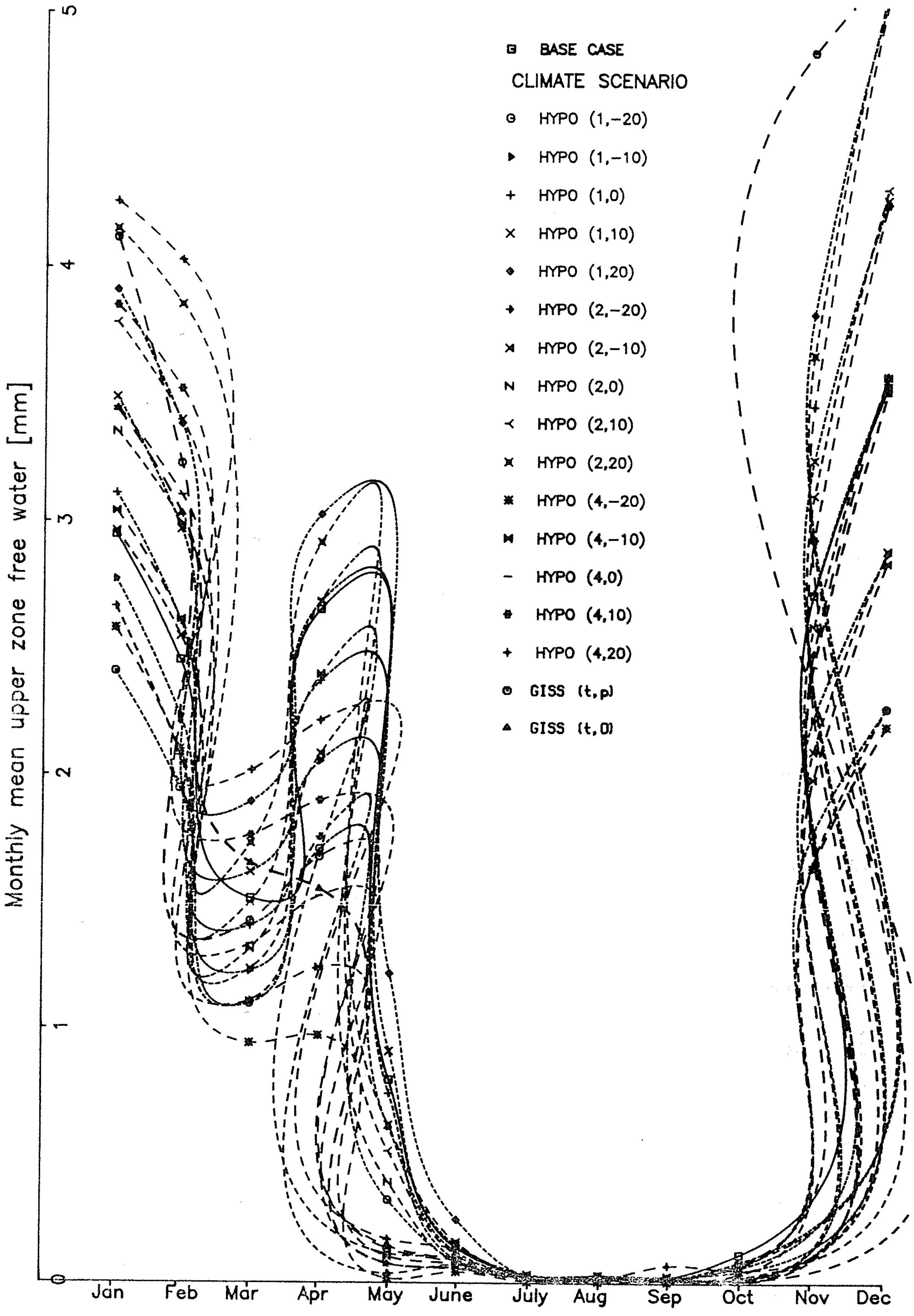

FIGURE 1
Mesochora catchment monthly mean upper zone free water for climate scenarios.

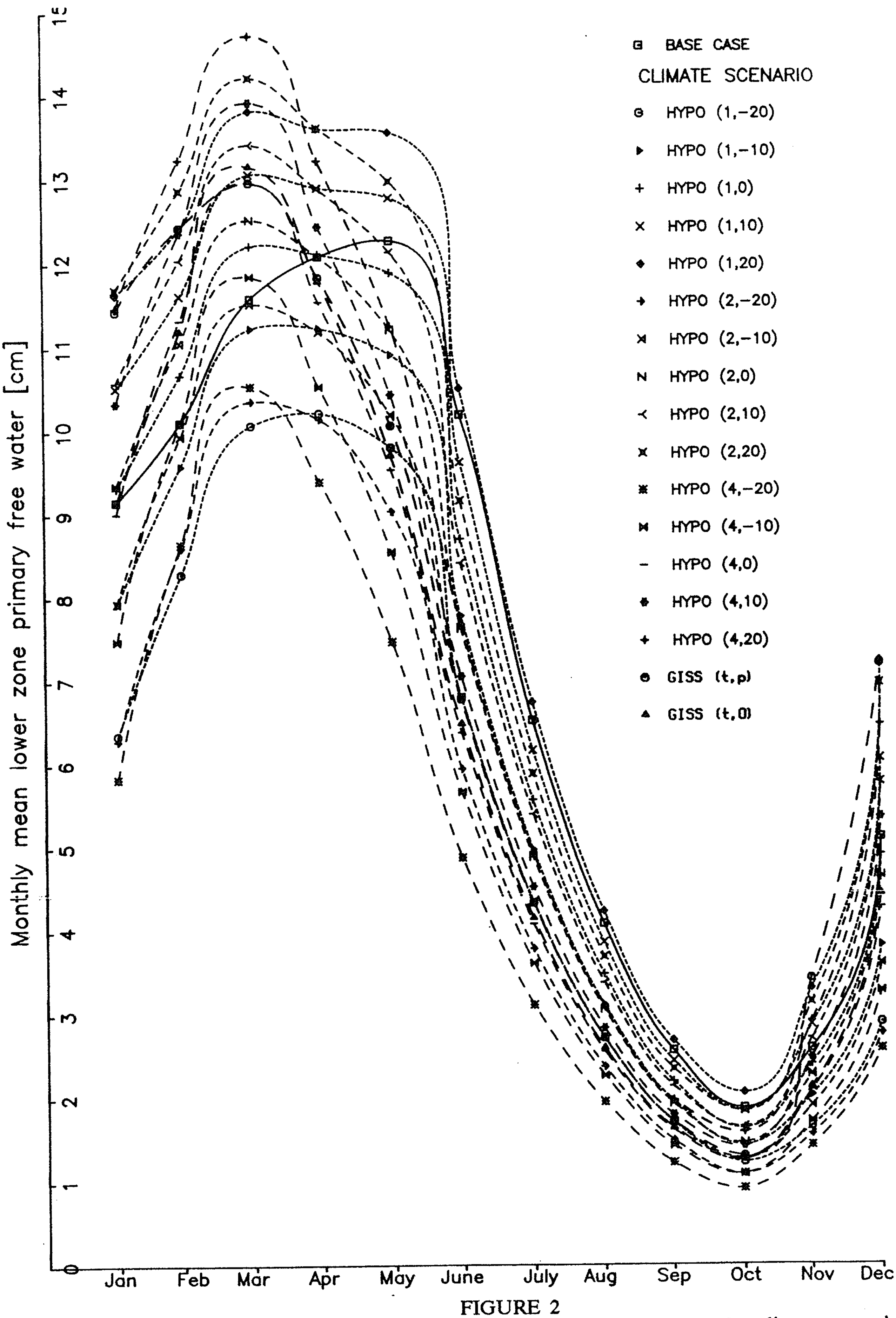

FIGURE 2
Mesochora catchment monthly mean lower zone primary free water for climate scenarios.

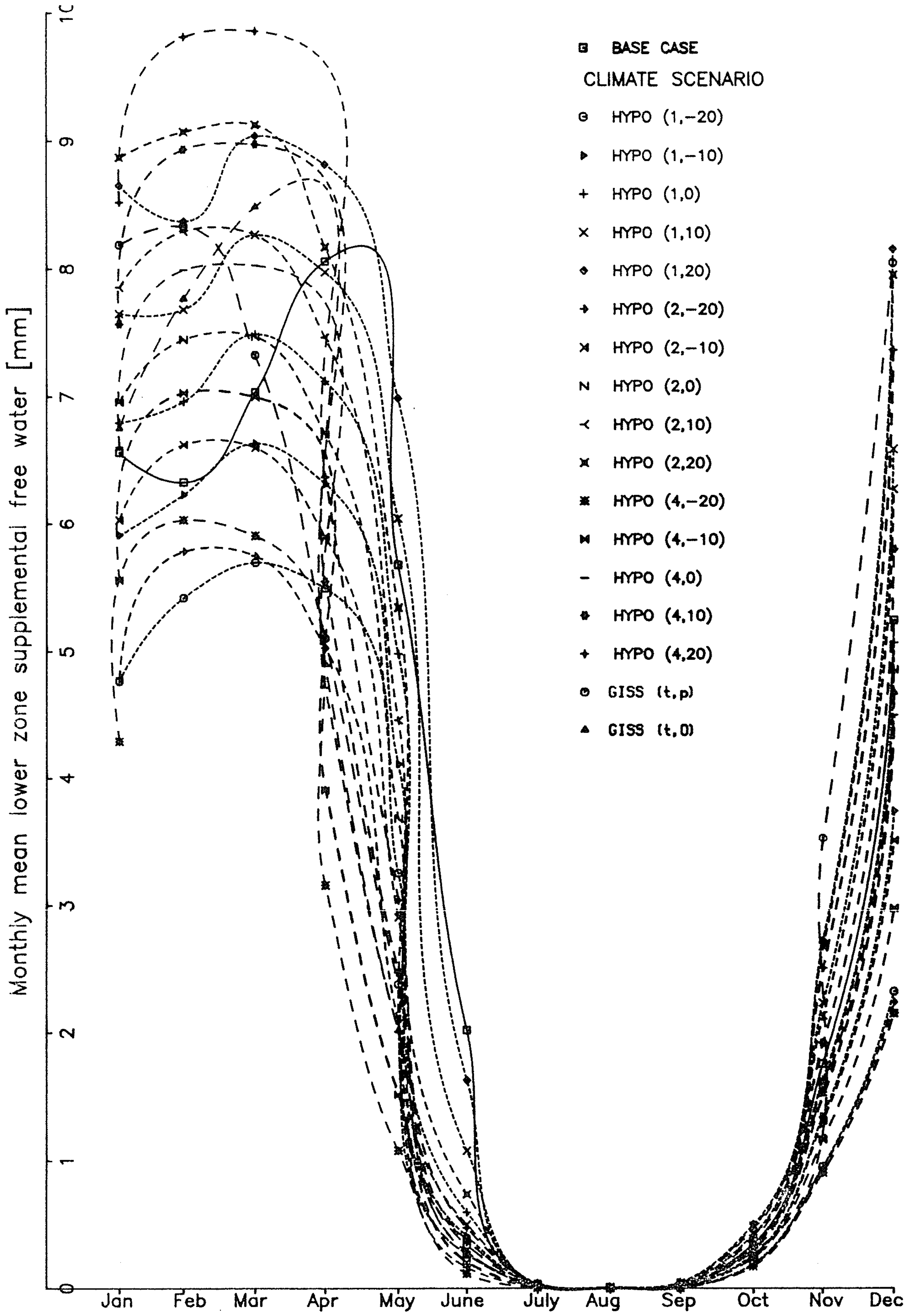

FIGURE 3
Mesochora catchment monthly mean lower zone supplemental free water for climate scenarios.

falling as rain would cause the winter soil moisture storage to augment, thereby leaving much more moisture for evapotranspiration in early spring. Furthermore, all the scenarios projected decreases in average spring and summer soil moisture.

* Significant differences in numerical results among the GISS and HYPO scenarios were noticed due to the wide range of the climate variable changes (e.g. the GISS precipitation increase in October was up 50%).

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