



EVALUATION OF HYDROLOGIC AND WATER RESOURCES RESPONSE TO METEOROLOGICAL DROUGHT IN THESSALY, GREECE

A. LOUKAS*, AND L. VASILIADES

Laboratory of Hydrology and Water Systems Analysis,
Department of Civil Engineering,
University of Thessaly, Volos, Greece

*E-mail: aloukas@civ.uth.gr



OBJECTIVES

- to identify different types of drought (agricultural, hydrological and water resources) using the meteorological drought index SPI in selected small, medium and large watersheds in the region of Thessaly, Greece.
- to identify the relationship between meteorological, hydrological and soil moisture drought, and water resources drought
- to identify the operational timescale of SPI for soil moisture hydrological and water resources drought
- to develop a drought preparedness plan in the region



HYDROLOGICAL DROUGHT IDENTIFICATION

- Assessment of hydrological drought severity using a water balance derived drought index (Vasiliades and Loukas, 2010)
- Use of a monthly water balance model to produce watershed runoff and soil moisture for small, medium and large watersheds
- Normalize and standardize the produced runoff and soil moisture timeseries for hydrological and soil moisture drought assessment
- Calculation of Standardized Precipitation Index at multiple timescales as meteorological drought index
- Identify the relationship between meteorological, hydrological and soil moisture drought with the response of respective indices
- Identify the response of drought indices to selective drought episodes

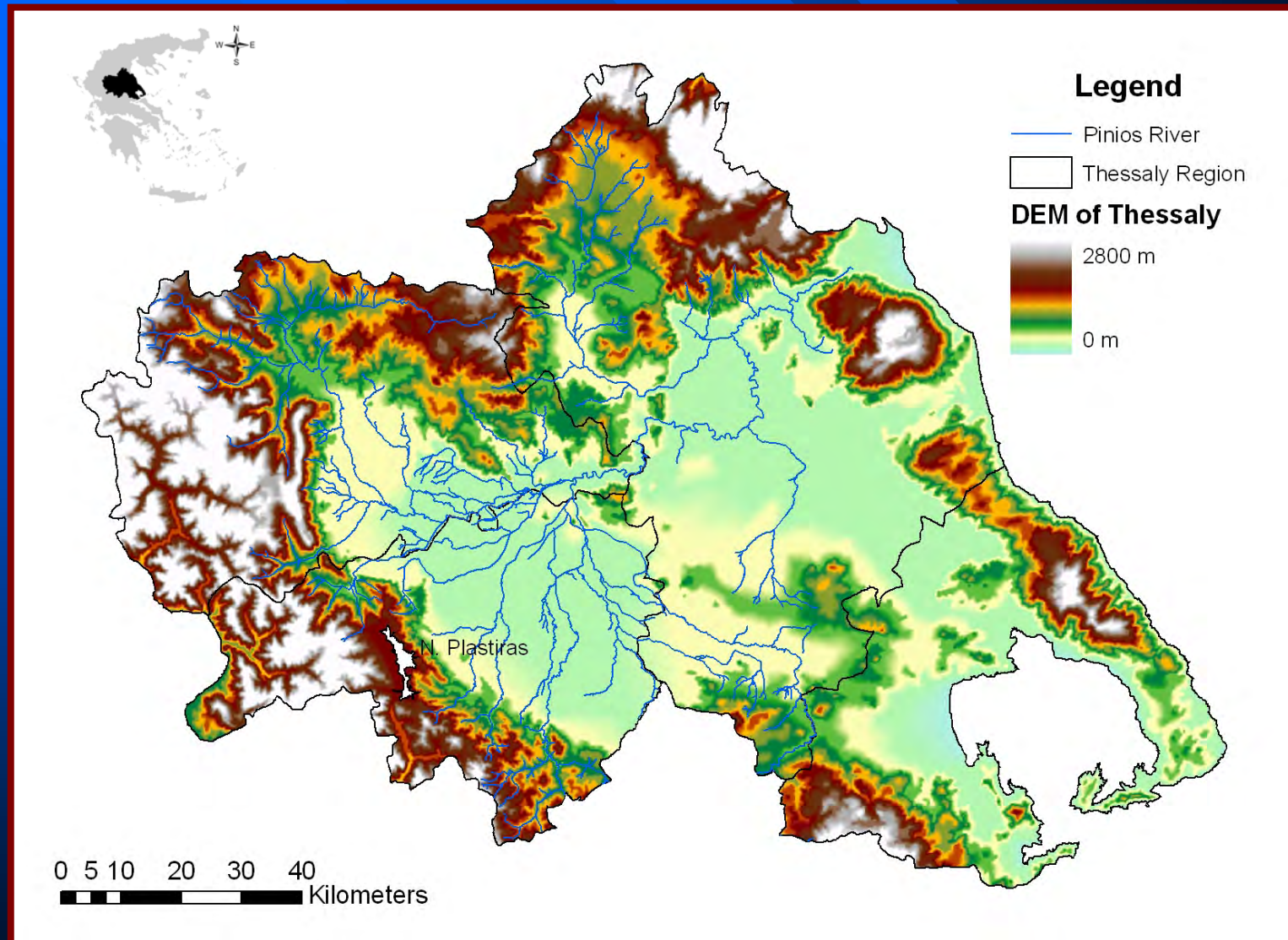


METHODOLOGY

- Use of a monthly water balance model to simulate hydrological cycle components (AET, soil moisture, runoff) in the seven (7) watersheds (the study watersheds have intermittent discharge observations at their outlets)
- Normalize and standardize the produced runoff and soil moisture timeseries for:
 - hydrological drought assessment → water balance derived drought index (Z_{WBI}) and
 - soil moisture drought assessment → soil moisture derived drought index (Z_{SMI})
- Comparison with calculated SPI at multiple timescales to find the operational drought index

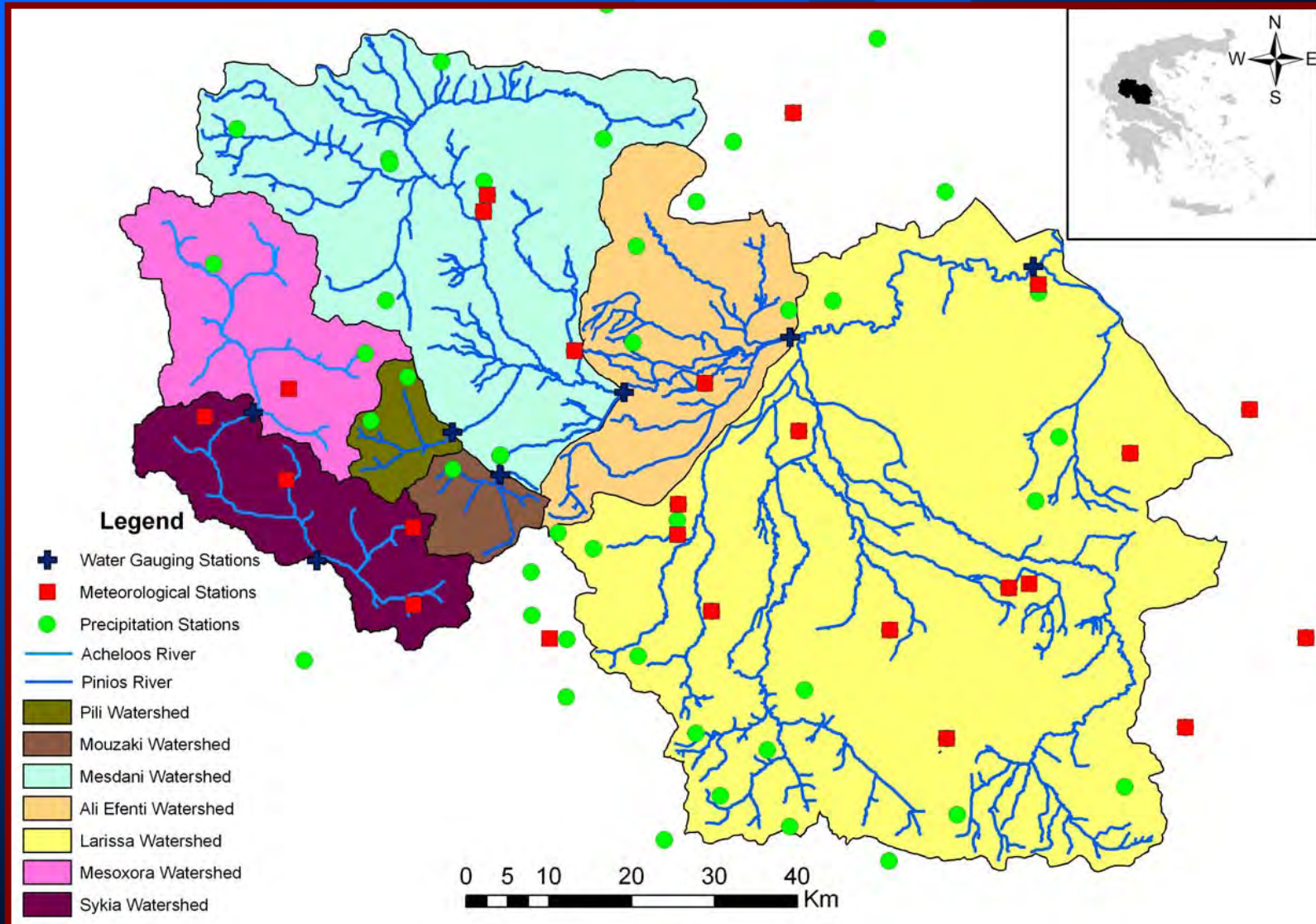


DEM OF THESSALY REGION





LOCATION OF THE STUDY WATERSHEDS AND DATABASE





CHARACTERISTICS OF THE STUDY AREAS

Attribute	Area (km ²)	Elevation range (m)	Mean Elevation (m)	Mean Annual Precipitation (mm)	Mean Annual Runoff (mm)	Runoff Coefficient
Pili	133	300 - 1800	949	1820	1130	0.62
Mouzaki	145	200 - 2000	838	1450	830	0.57
Mesdani	2055	180-2000	660	985	600	0.61
Ali Efenti	2869	150-2000	555	890	420	0.47
Larissa	6591	70-2000	451	720	290	0.40
Mesoxora	615	700 - 2300	1400	1860	1150	0.62
Sykia	1155	500 - 2300	1288	1875	1290	0.69



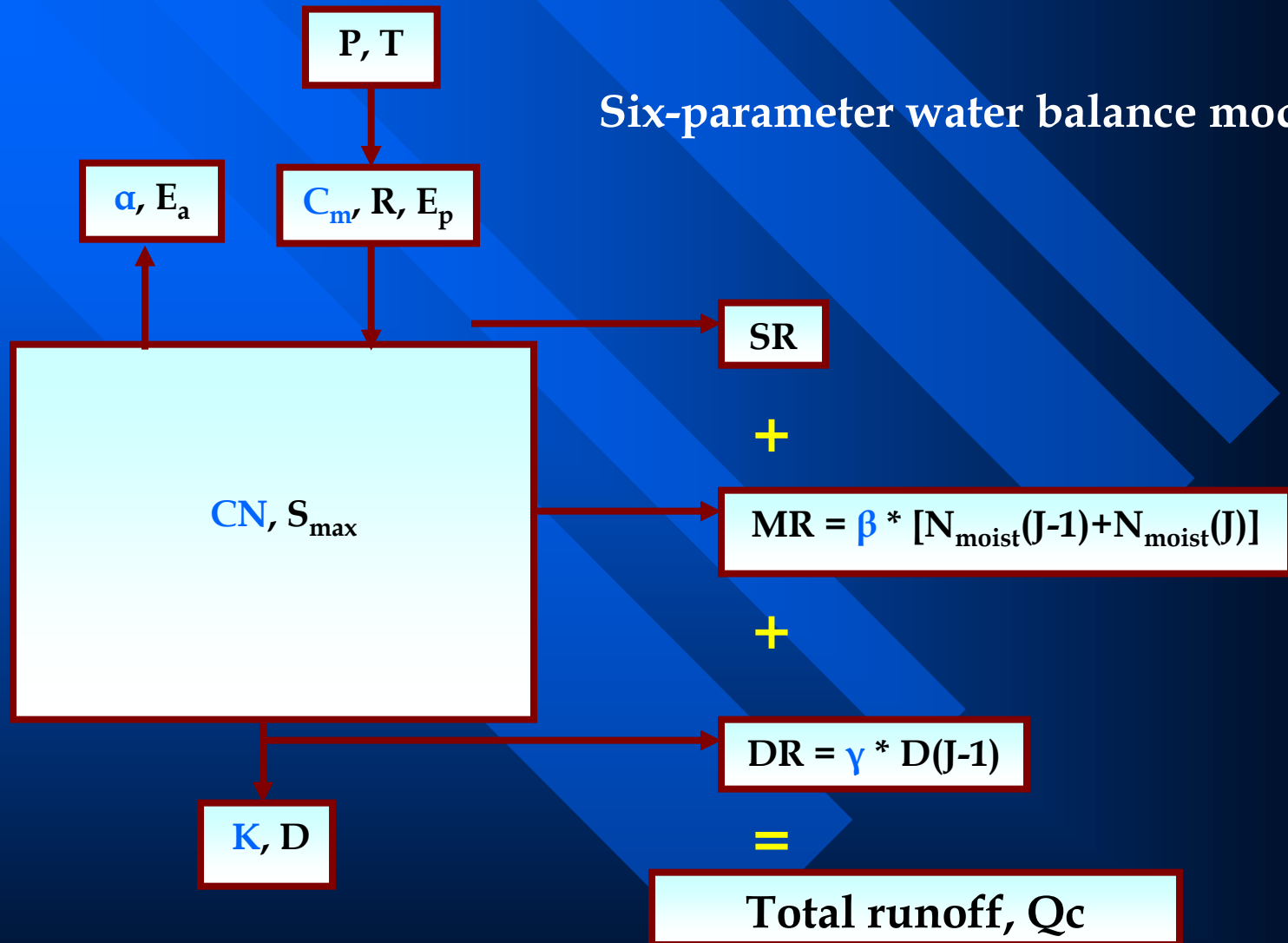
THE UTHBAL MODEL

- A monthly conceptual water balance (UTHBAL) model was developed by Loukas et al., (2007)
- Three inputs: Areal precipitation, mean areal temperature and potential evapotranspiration
- The precipitation is separated into rainfall and snowfall
- The rain/snow percentage have been estimated using a logistic relationship based on mean monthly air temperature
- The snowmelt is estimated with the simple degree-day method
- Total watershed runoff is divided into three components: the surface runoff, the medium runoff, and the baseflow runoff using a soil moisture mechanism
- Outputs: AET, soil moisture, groundwater and surface runoff



WATER BALANCE MODEL (UTHBAL)

Six-parameter water balance model





HYDROLOGICAL MODEL PROCEDURE

- Six (6) parameters of the water balance model have to be optimized
- Optimization was done using the global multistart Generalised Reduced Gradient Algorithm
- The objective function of the above calibration procedure was defined as:

$$Eff = 1 - \frac{\sum_{i=1}^n (Q_{obs_i} - Q_{sim_i})^2}{\sum_{i=1}^n (Q_{obs_i} - \overline{Q_{obs}})^2}$$

where,

Q_{obs_i} is the observed flow on month i ,

Q_{sim_i} is the simulated flow on month i , and

$\overline{Q_{obs}}$ is the average observed flow for the simulation period



ESTIMATION OF INPUT DATA SETS

- **Mean monthly basin wide temperature:** temperature lapse rate from 27 meteorological stations adjusted for the mean elevation
- **Potential evapotranspiration:** Thornthwaite method (based on mean monthly basin wide temperature)
- **Areal Precipitation: Modified Thiessen method**
 - The weighted coefficients of the Thiessen method were calculated in the GIS
 - Adjusted with the precipitation gradient for the mean elevation of each watershed
 - Linear relationship between precipitation and elevation (high correlation values in all watersheds, $r > 0.90$)



RECONSTRUCTION OF RUNOFF AND SOIL MOISTURE

➤ UTHBAL optimisation results

Watershed	Eff	DV(%)	R	Calibration Period
Pili	0.72	0.96	0.85	Oct 60 - Sep 94
Mouzaki	0.72	-0.80	0.85	Oct 60 - Sep 85, Oct 87 - Sep 94
Mesdani	0.80	-1.98	0.90	Oct 60 - Sep 71
Ali Efenti	0.78	-1.28	0.89	Oct 60 - Dec 69, Feb 72 - Jun 94
Larissa	0.76	0.39	0.87	Oct 60 - Feb 67, Jan 69 - Mar 91
Mesoxora	0.71	-0.75	0.84	Oct 60 - Sep 94
Sykia	0.72	-0.99	0.85	Oct 60 - Sep 94

➤ Extension of calculated (synthetic) runoff and soil moisture timeseries for the period Oct 1960 to Sep 2002

➤ Normalization through Box-Cox transformation

$$Y = \begin{cases} \frac{X^\lambda - 1}{\lambda}, & \lambda \neq 0 \\ \ln(X), & \lambda = 0 \end{cases}$$

➤ Standardization to the normal distribution (Z_{WBI} and Z_{SMI})

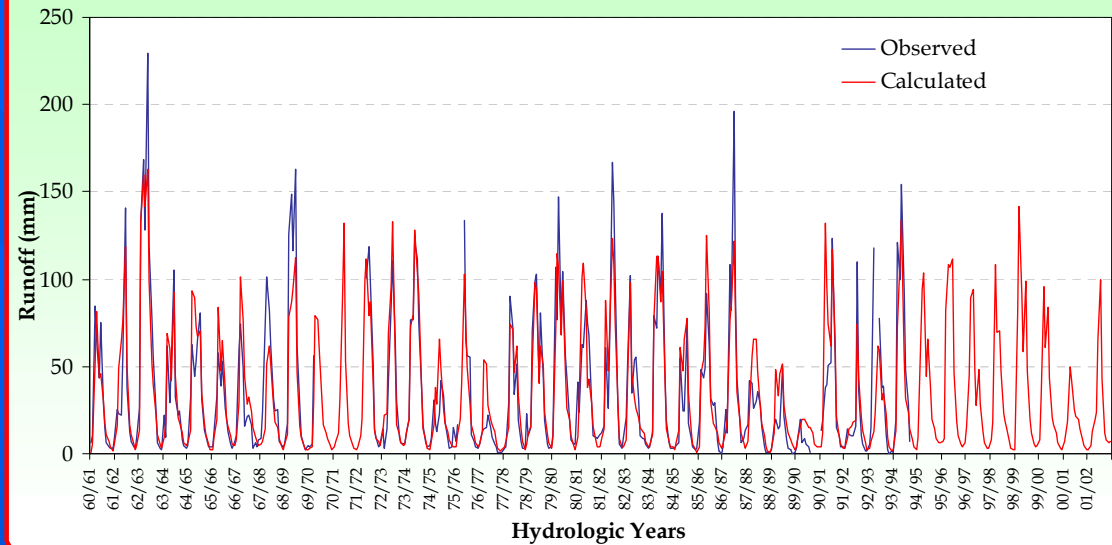
$$Z_{WBI} = \frac{Y - \bar{Y}}{\sigma_Y}$$



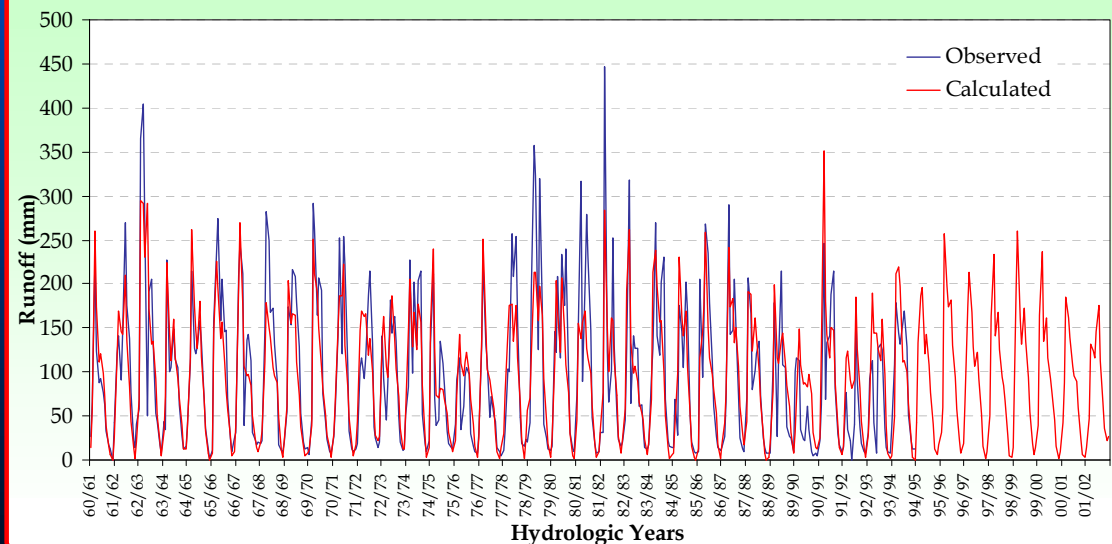
COMPARISON OF OBSERVED AND SIMULATED HYDROGRAPHS

Department of Civil Engineering,
University of Thessaly

ALI EFENTI WATERSHED



MESOXORA WATERSHED





THE STANDARDIZED PRECIPITATION INDEX

- The SPI calculation for any location is based on the long-term precipitation record for various time scales
- Wetter and drier climates can be represented in the same way, because SPI is a standardized index
- This long-term record is fitted to a Gamma probability distribution, which is then transformed into a Normal distribution with mean SPI zero (0) and SPI variance one (1)
- Maximum likelihood solutions were obtained for estimation of Gamma distribution parameters
- Areal precipitation was used for estimation of SPI at 1-, 2-, 3-, 4-, 5-, 6-, 9-, 12-, and 24-month time scales in all study watersheds



RESULTS

Best correlations between meteorological-hydrological and soil moisture drought indices

SPI - Runoff Z_{WBI}

Watershed	Time scale of SPI (r)
Mouzaki	SPI-3month (0.76)
Pili	SPI-2month (0.79)
Mesdani	SPI-3month (0.90)
Ali Efenti	SPI-3month (0.86)
Larissa	SPI-4month (0.85)
Mesoxora	SPI-2month (0.84)
Sykia	SPI-2month (0.85)

SPI - Soil Moisture Z_{SMI}

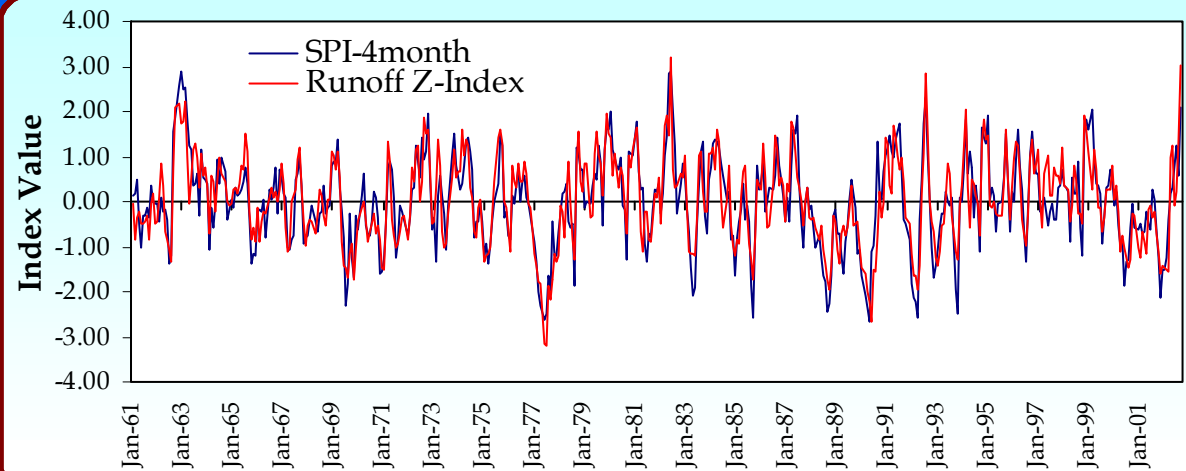
Watershed	Time scale of SPI (r)
Mouzaki	SPI-1month (0.76)
Pili	SPI-1month (0.78)
Mesdani	SPI-2month (0.88)
Ali Efenti	SPI-2month (0.85)
Larissa	SPI-3month (0.84)
Mesoxora	SPI-1month (0.84)
Sykia	SPI-1month (0.84)



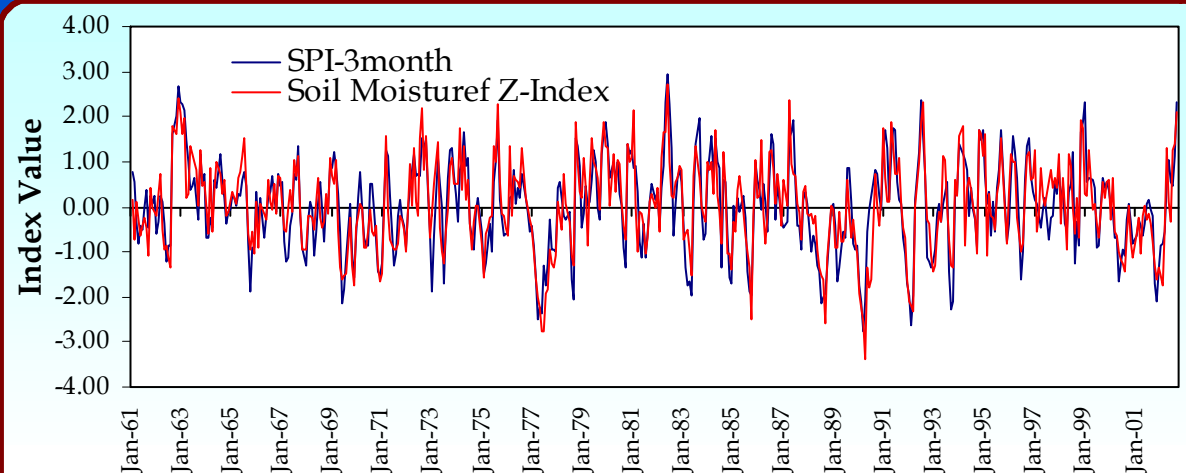
Timeseries of meteorological, hydrological and soil moisture drought indices

LARISSA WATERSHED

SPI - Runoff Z-Index (Z_{WBI})



SPI - Soil Moisture Z-Index (Z_{SMI})



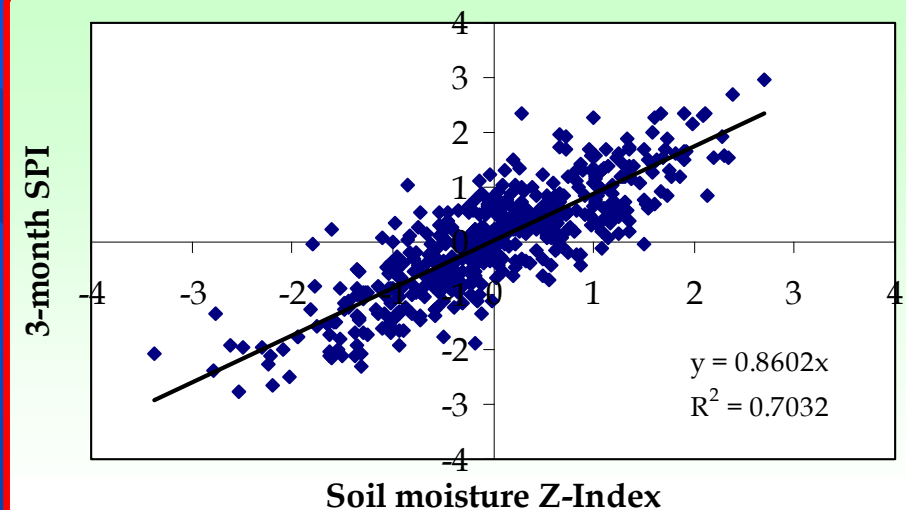
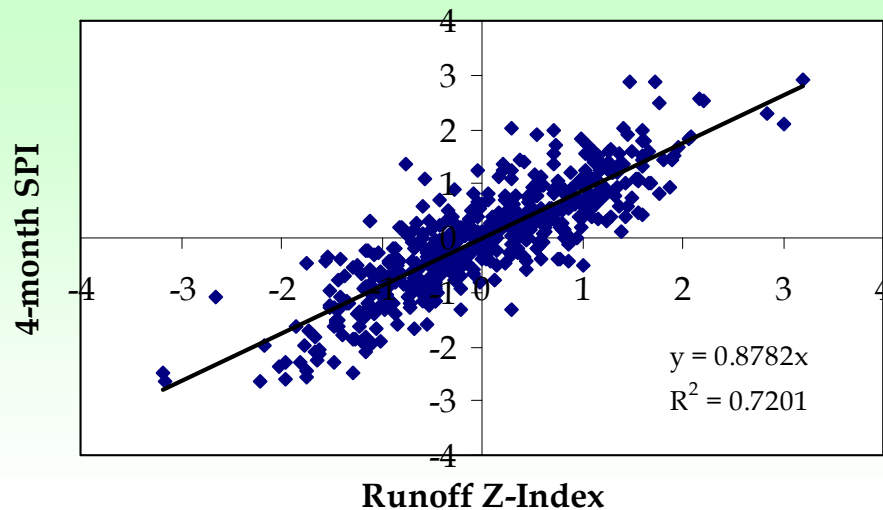


Scattergraphs of meteorological-hydrological and soil moisture drought indices

LARISSA WATERSHED

SPI - Runoff Z-Index (Z_{WBI})

SPI - Soil Moisture Z-Index (Z_{SMI})

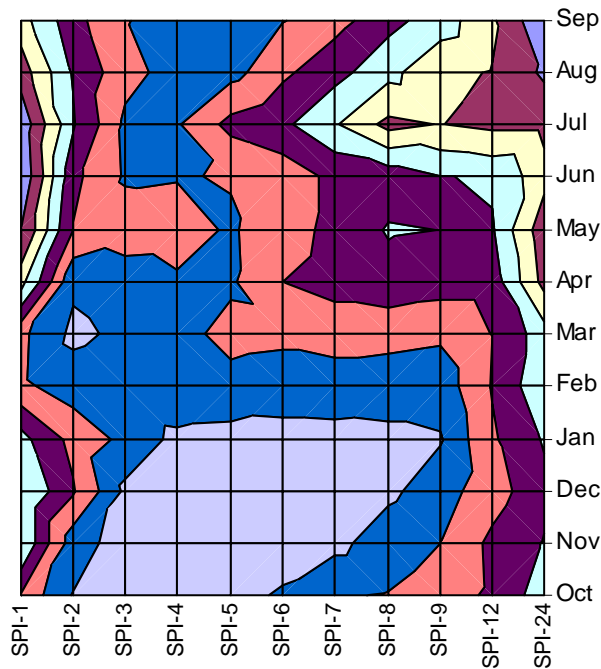
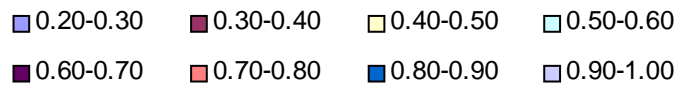




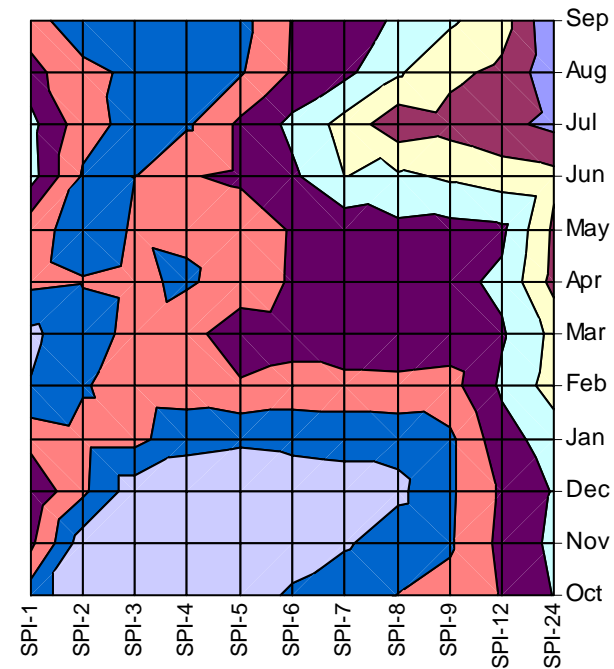
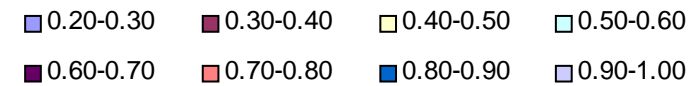
Monthly correlations between meteorological-hydrological and soil moisture drought indices

LARISSA WATERSHED

SPI - Runoff Z-Index (Z_{WBI})



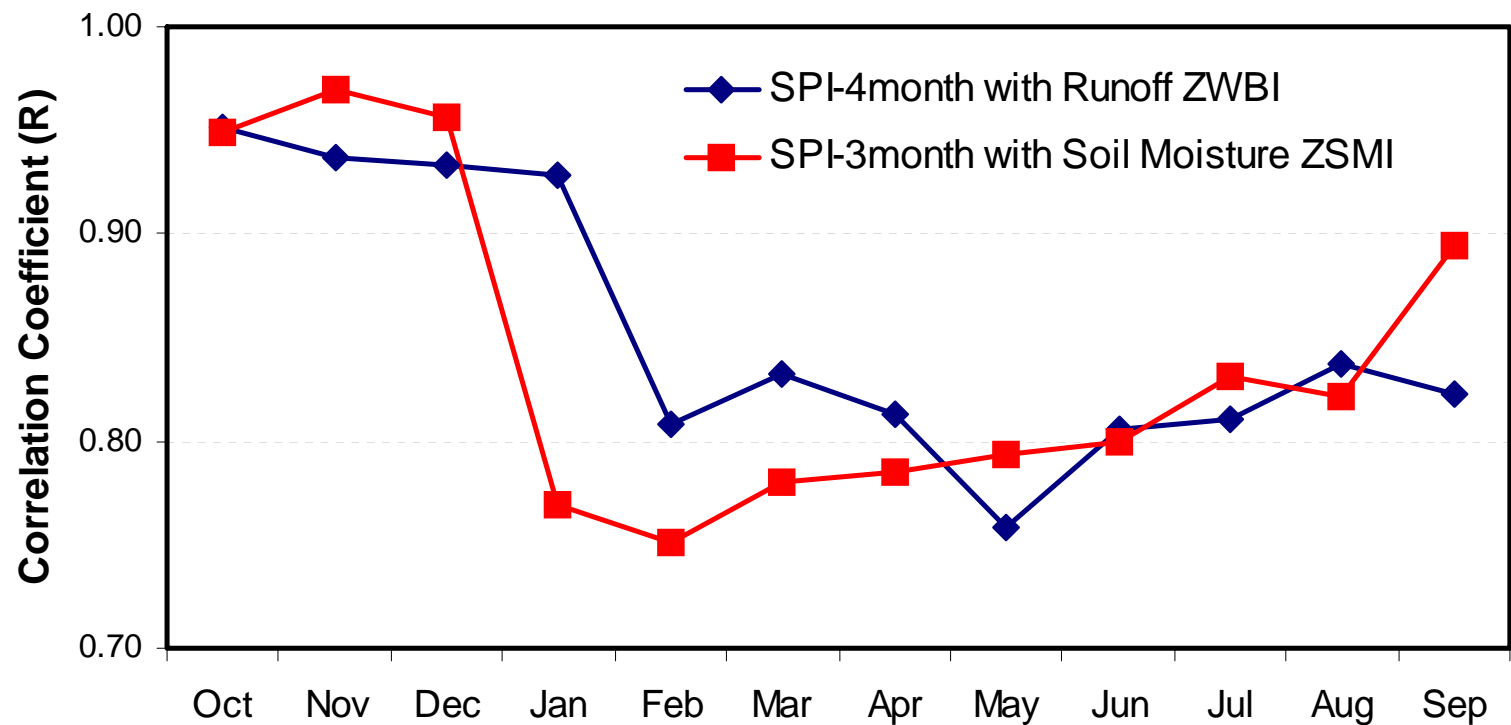
SPI - Soil Moisture Z-Index (Z_{SMI})





Best monthly correlations between meteorological-hydrological and soil moisture drought indices

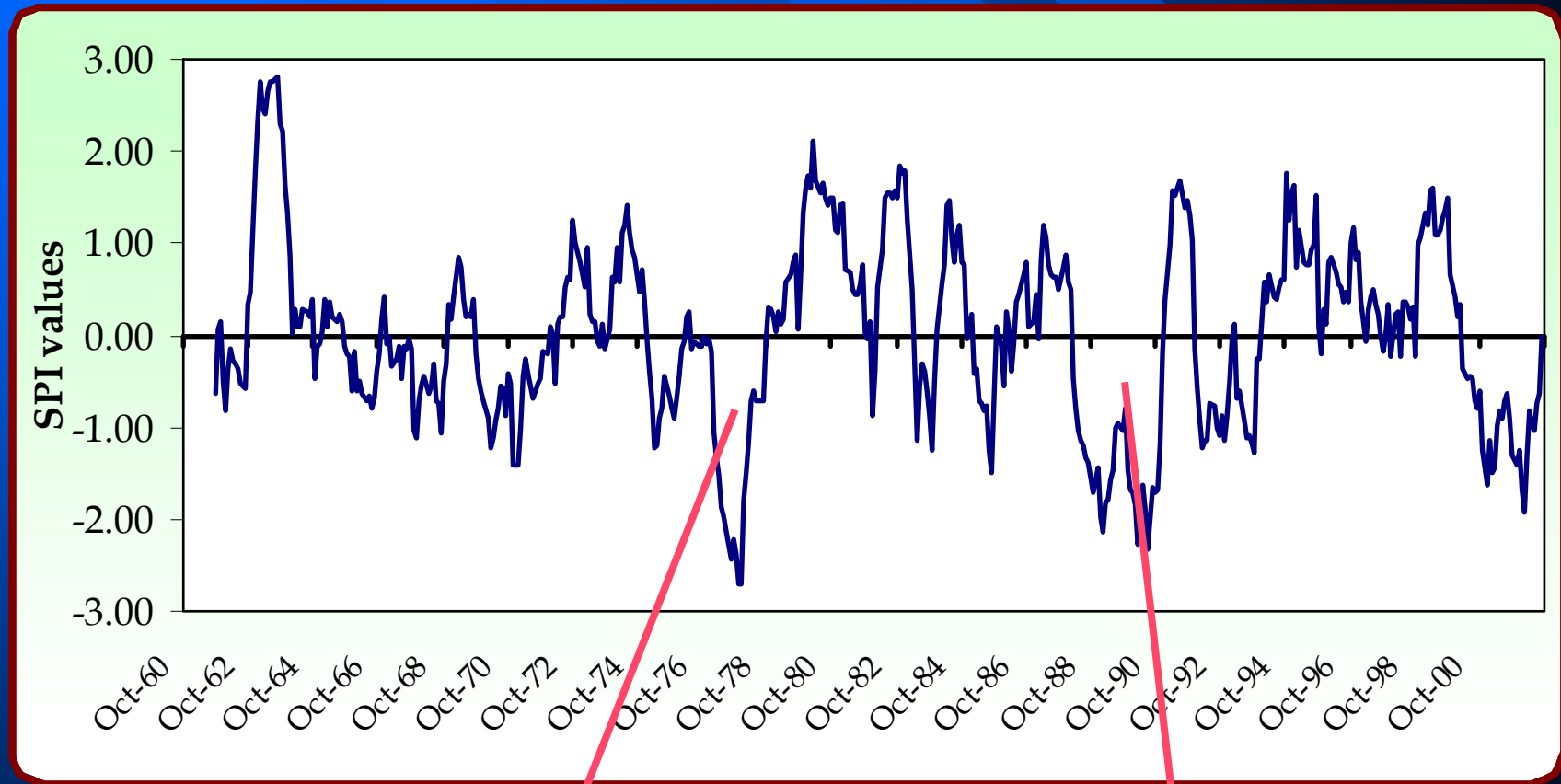
LARISSA WATERSHED





SELECTIVE HISTORICAL DROUGHT EVENTS

12-month SPI for Larissa Watershed (Loukas & Vasiliades, 2004)



**The 1977-1978
drought episode**

**The 1988-1990
drought episode**



Best correlations between meteorological and hydrological drought indices for the selective historical events

Watershed	Period Oct 60-Sep 02 Time scale of SPI (r)	Period Oct 76-Sep78 Time scale of SPI (r)	Period Oct87-Sep90 Time scale of SPI (r)
Mouzaki	SPI-3month (0.76)	SPI-4month (0.85)	SPI-3month (0.87)
Pili	SPI-2month (0.79)	SPI-3month (0.77)	SPI-3month (0.83)
Mesdani	SPI-3month (0.90)	SPI-4month (0.92)	SPI-5month (0.90)
Ali Efenti	SPI-3month (0.86)	SPI-5month (0.93)	SPI-5month (0.92)
Larissa	SPI-4month (0.85)	SPI-5month (0.93)	SPI-6month (0.86)
Mesoxora	SPI-2month (0.84)	SPI-4month (0.87)	SPI-3month (0.87)
Sykia	SPI-2month (0.85)	SPI-3month (0.83)	SPI-3month (0.90)



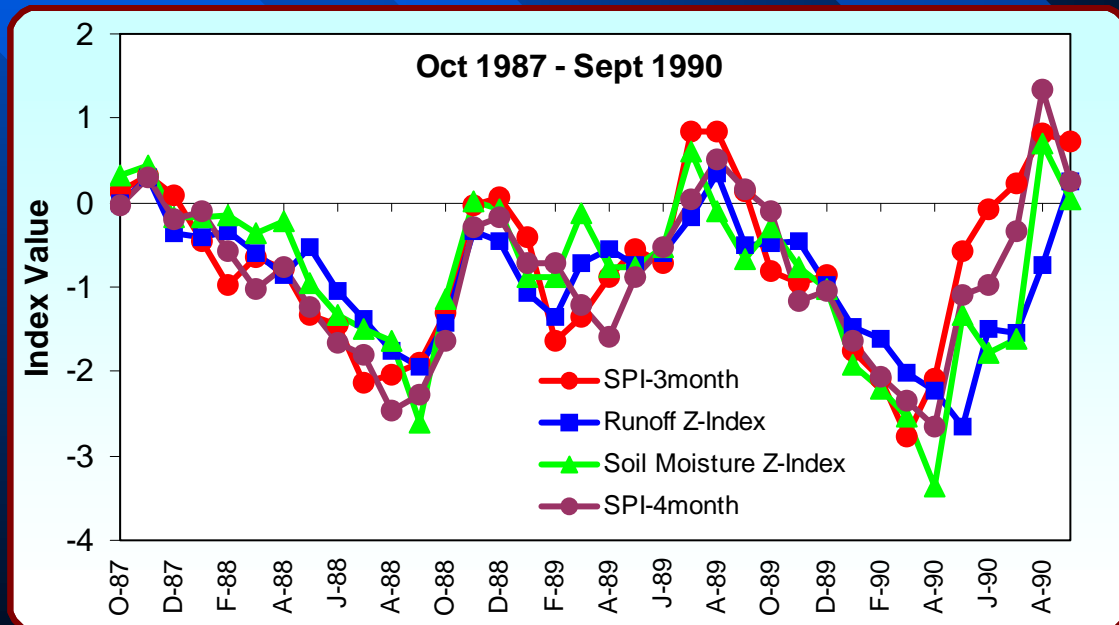
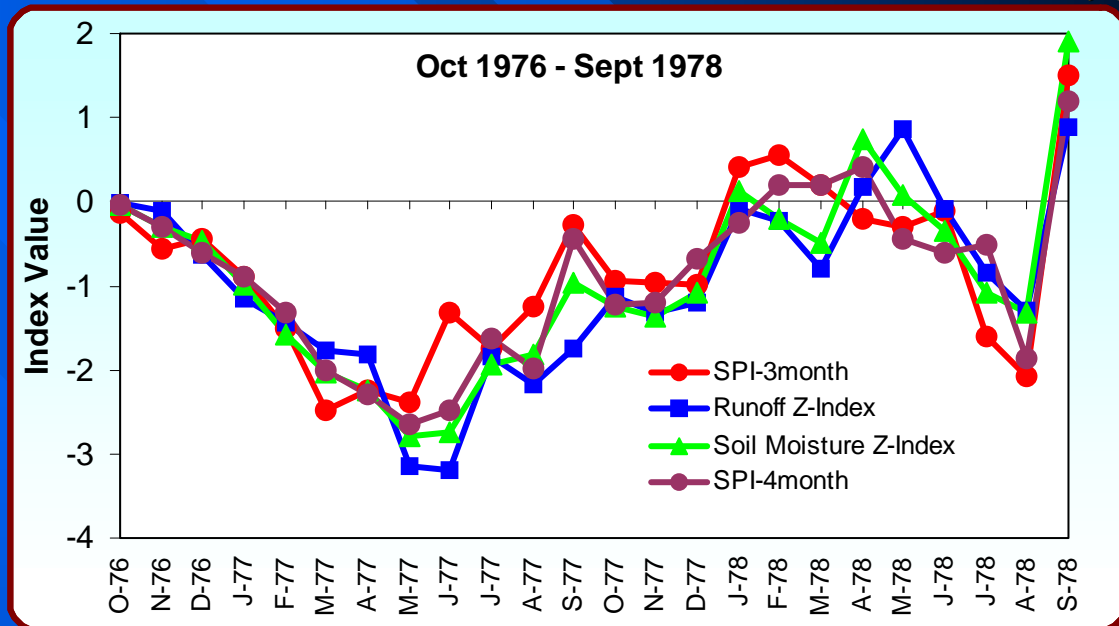
Best correlations between meteorological and soil moisture drought indices for the selective historical events

Watershed	Period Oct 60-Sep 02 Time scale of SPI (r)	Period Oct 76-Sep78 Time scale of SPI (r)	Period Oct87-Sep90 Time scale of SPI (r)
Mouzaki	SPI-1month (0.76)	SPI-3month (0.85)	SPI-3month (0.84)
Pili	SPI-1month (0.78)	SPI-1month (0.79)	SPI-2month (0.83)
Mesdani	SPI-2month (0.88)	SPI-3month (0.91)	SPI-4month (0.87)
Ali Efenti	SPI-2month (0.85)	SPI-4month (0.91)	SPI-4month (0.88)
Larissa	SPI-3month (0.84)	SPI-5month (0.95)	SPI-5month (0.89)
Mesoxora	SPI-1month (0.84)	SPI-3month (0.86)	SPI-3month (0.86)
Sykia	SPI-1month (0.84)	SPI-2month (0.85)	SPI-2month (0.87)



Response of Drought Indices to selective historical events

LARISSA WATERSHED





WATER RESOURCES DROUGHT IDENTIFICATION

- The Plastiras Lake, situated in a mountainous part of Western Thessaly, is a multipurpose reservoir used for hydropower, irrigation, water supply and recreation. These competitive uses raise various conflicts between groups of different interests (farmers, residents, ecologists, hotel owners).
- Use of reservoir storages as water use index
- Normalize and standardize the reservoir storages for water resources drought assessment
- Calculation of Standardized Precipitation Index at multiple timescales as meteorological drought index

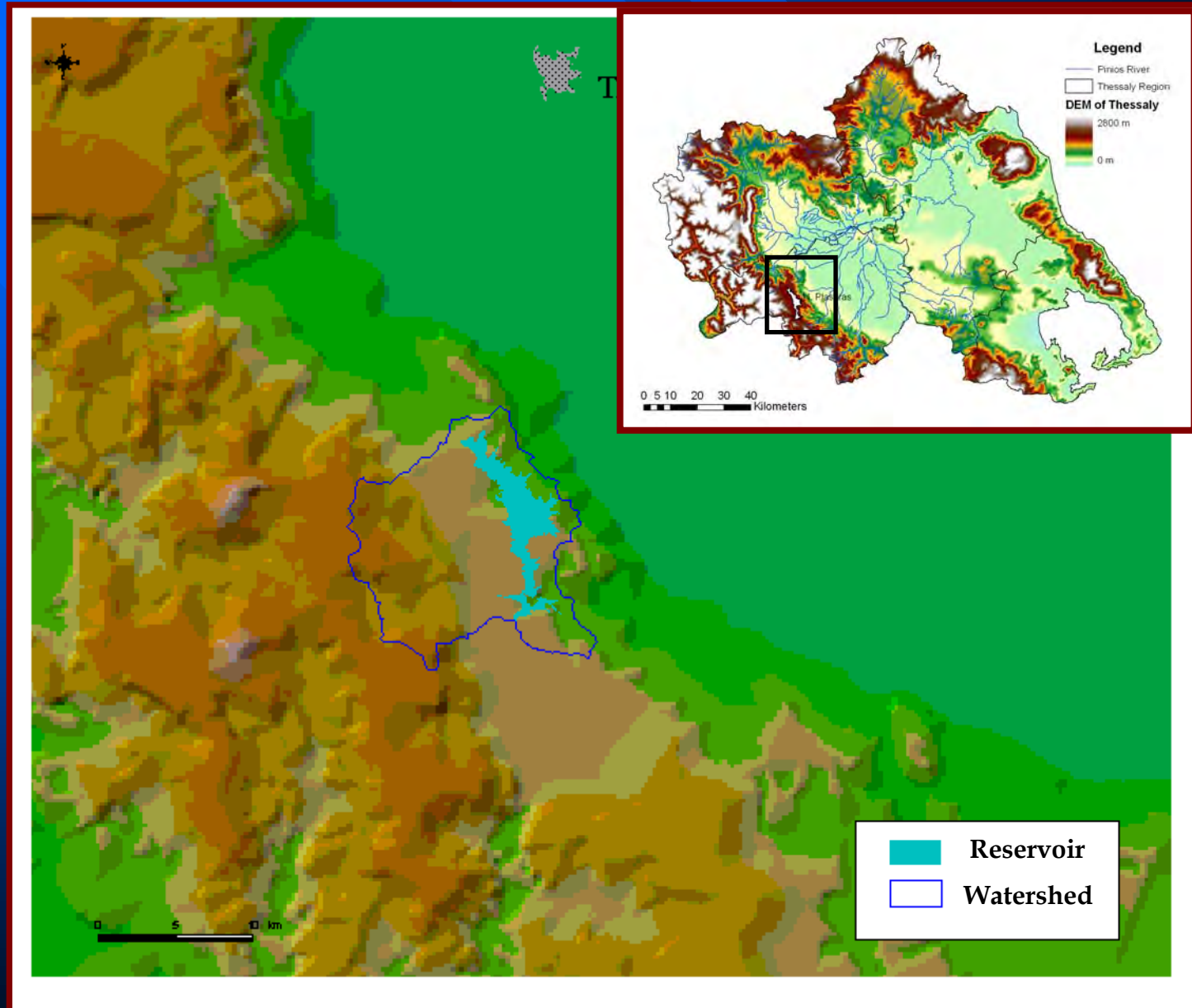


Plastiras basin and reservoir characteristics

- Basin area 161.3 km²
- Maximum basin altitude 2140 m, mean altitude 1459 m
- Mean annual runoff 147 hm³ (1029 mm)
- Arch dam, height 83 m
- Reservoir capacity 362 hm³, net capacity 286 hm³, maximum area 25 km²
- Intake level +776 m, spill level +792 m
- Installed power capacity 130 MW, hydraulic head 577 m
- Annual water demand 160 hm³
 - 145 hm³ for irrigation, 15 hm³ for water supply



DEM



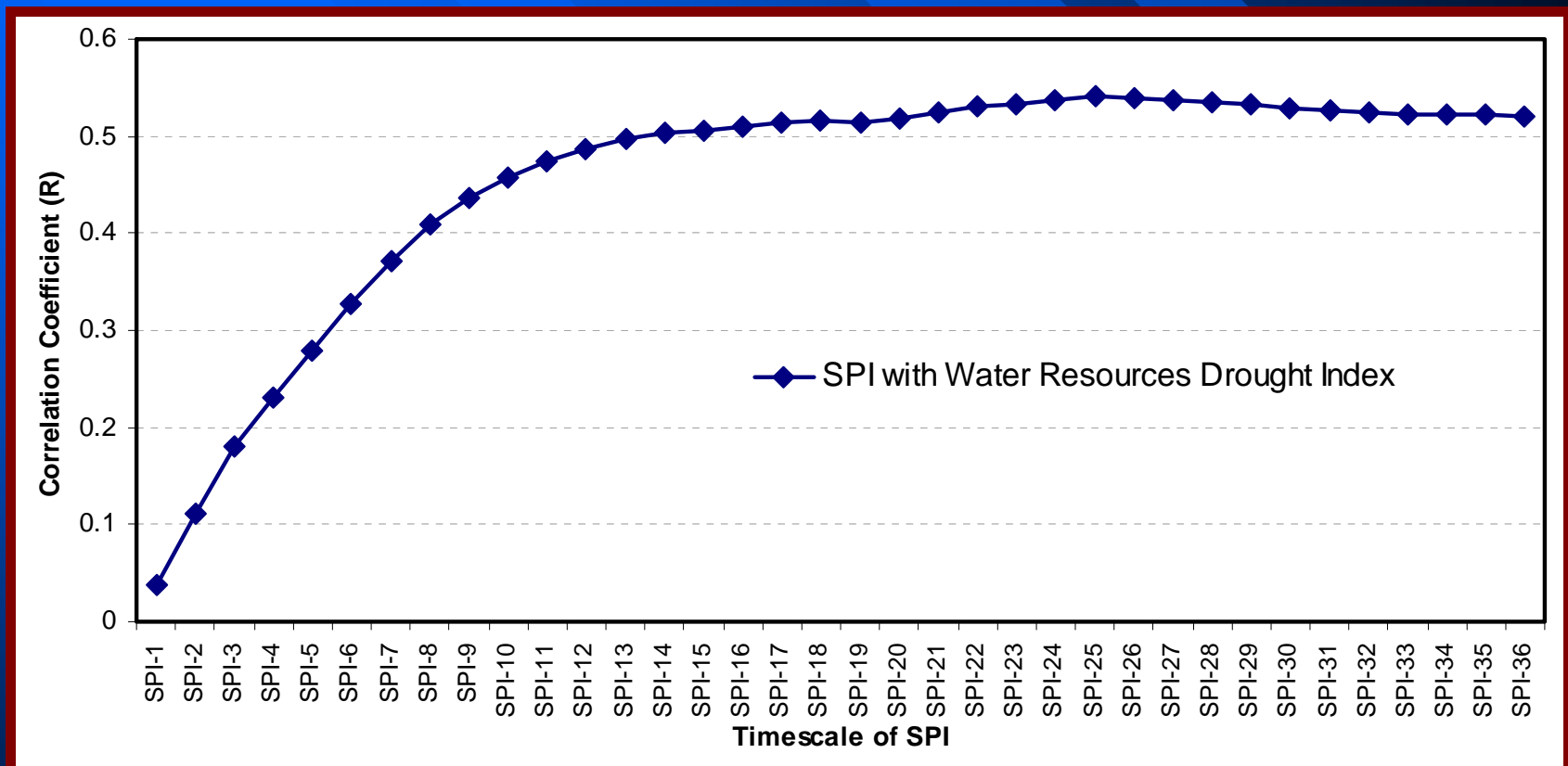


VIEW OF THE SOUTHERN PART OF PLASTIRAS LAKE



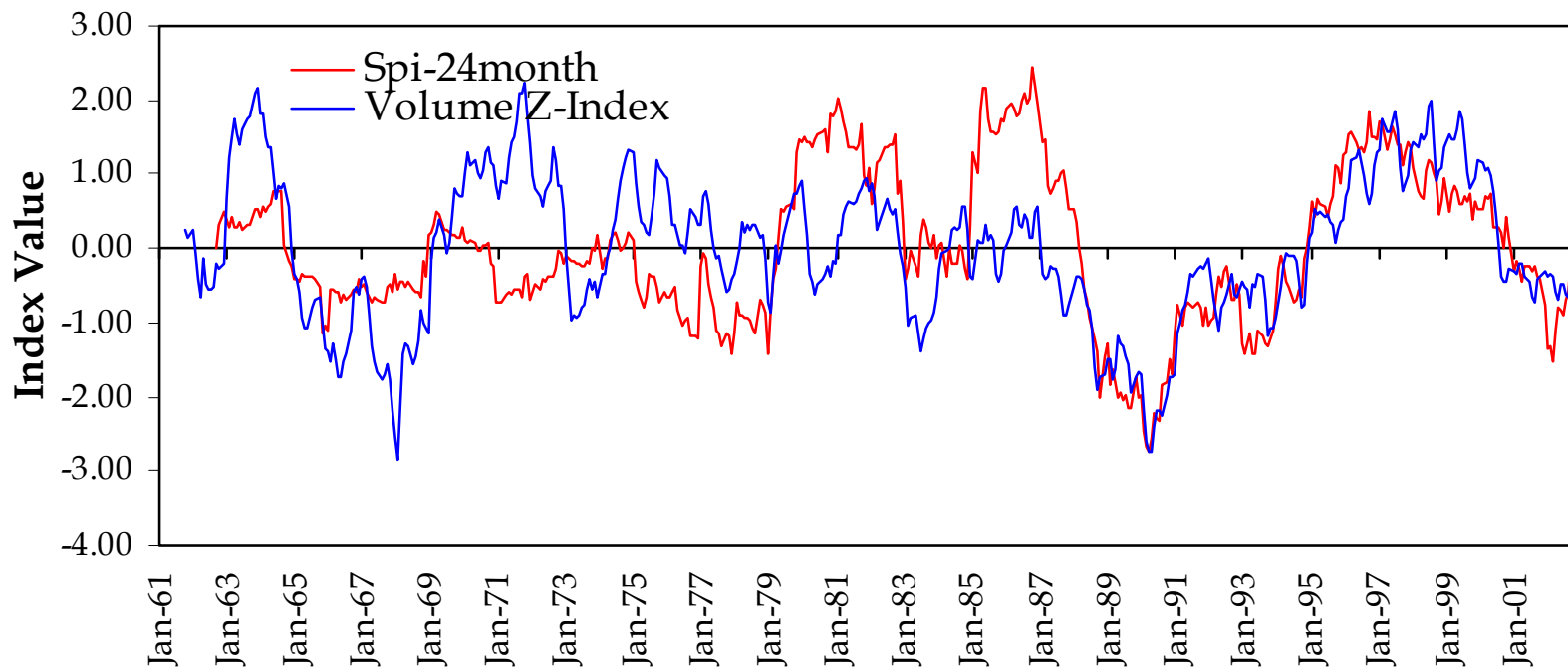


Correlations between meteorological and water resources drought indices



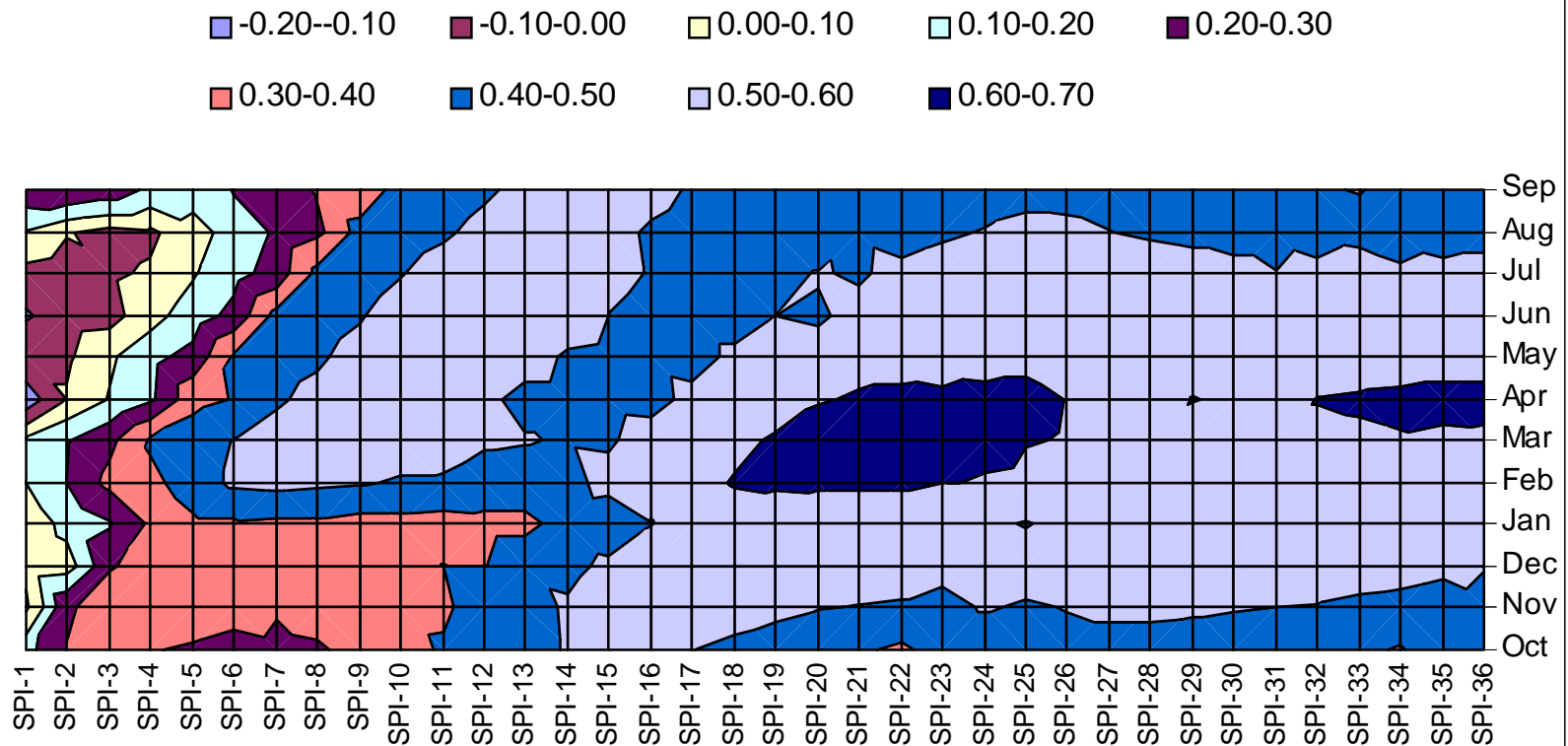


Timeseries of meteorological, and water resources drought indices





Monthly correlations between meteorological and water resources drought indices





CONCLUDING REMARKS

- Soil moisture is more responsive to meteorological dry conditions than runoff
- Care should be given in the choice of SPI timescale for drought identification (it depends on the size and characteristics of the watershed and the runoff processes)
- The Standardized Precipitation Index could be used as operational tool to identify hydrological, soil moisture and water resources drought



FUTURE RESEARCH

- Use of geomorphological watershed characteristics (area, basin slope, wetness index etc.) and runoff generation processes to establish an independent stable relationship for identification of SPI timescale in a given watershed
- Consideration of snow hydrology processes in the development of a drought index (very important for mountainous areas)



REFERENCES

- Loukas, A., Vasiliades, L., 2004. Probabilistic analysis of drought spatiotemporal characteristics in Thessaly Region, Greece. *Natural Hazards and Earth System Sciences*, 4(5-6), 719-731.
- Loukas, A., Mylopoulos, N., Vasiliades, L., 2007. A modeling system for the evaluation of water resources management strategies in Thessaly, Greece. *Water Resources Management*, 21(10), 1673-1702.
- Vasiliades, L., Loukas, A., Liberis, N., 2010. A water balance derived drought index for Pinios river basin, Greece. *Water Resources Management* (submitted).