SIMPLE WATER BALANCE MODEL USING A GEOGRAPHICAL INFORMATION SYSTEM

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Abstract

A simple distributed water balance model is presented which simulates the hydrological processes in monthly time step using a Geographical Information System and its object oriented programming language. Model inputs (precipitation, temperature) and outputs (evapotranspiration, water storage in different conceptual reservoirs, runoff) are given in distributed format in grids with a cell size of 4 square kilometres. Successive transformations of precipitation are done assuming an interconnected system of hypothetical reservoirs representing snow accumulation, soil moisture and groundwater. The model uses only four parameters, namely imperviousness, soil storage capacity and recession coefficients of soil moisture and groundwater. The model is applied to the Acheloos River basin in Western Greece and measured river discharge at a hydrometric station is used for calibration and verification. Despite of its simplicity and parsimony of parameter the model yields a very satisfactory reproduction of measured discharge also providing accumulated runoff in any location of the river network by implementing utilities of a Geographical Information System.

Study area: Acheloos water basin upstream of the Kremasta dam site (area 3424 km²), Western Greece
Data period: October 1980 - June 1988
Geographical data : Digital terrain model (DTM)
Sites of the hydrometeorological stations
Geology of the basin
Hydrographic network
Hydrometeorological data: Precipitation
Temperature
Relative humidity
Wind speed
Sunshine duration
GIS: ArcView
Programming language: Avenue

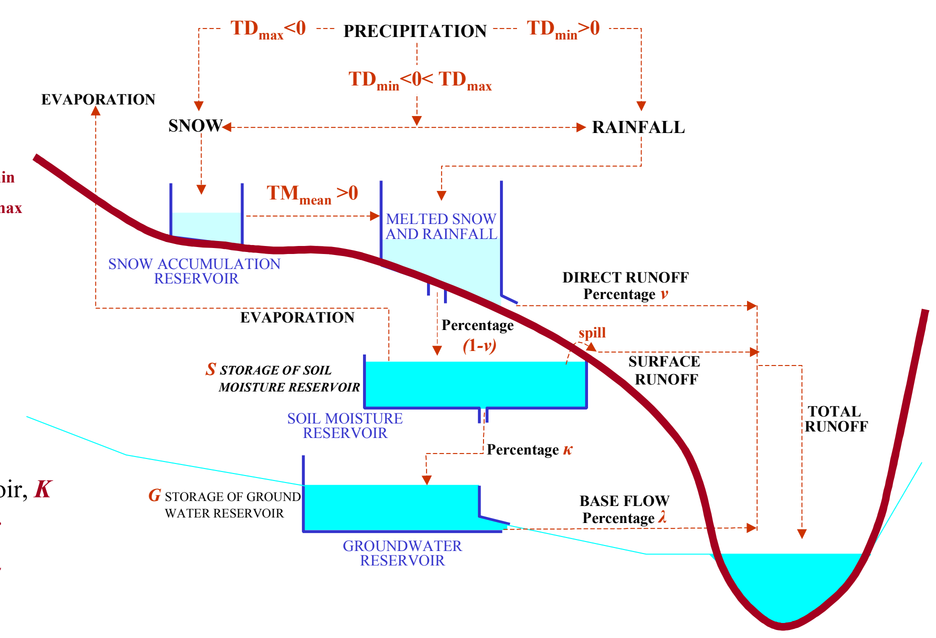
Water balance model

General scheme

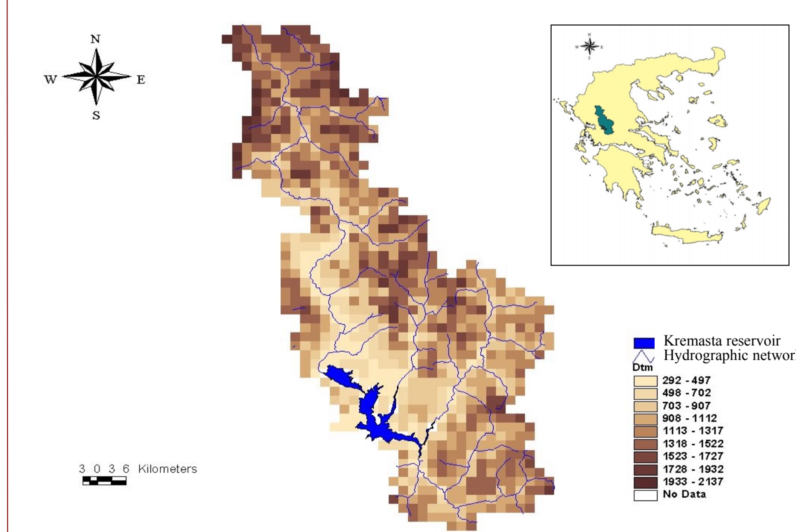
Input variables:
- ★ Precipitation, *P*
- ★ Potential evapotranspiration, E_p
- ★ Average monthly temperature, TM_{mean}
- ★ Minimum mean daily temperature, TD_{min}
- ★ Maximum mean daily temperature, TD_{max}

Output variables:
- ★ Storage of soil moisture reservoir, *S*
- ★ Storage of ground water reservoir, *G*
- ★ Actual evapotranspiration, **RE**
- ★ Total runoff, *Q*

Model parameters:
- ★ Percentage of imperviousness surface, *ν*
- ★ Storage capacity of soil moisture reservoir, *K*
- ★ Recession coefficient of soil moisture, *κ*
- ★ Recession coefficient of ground water, *λ*

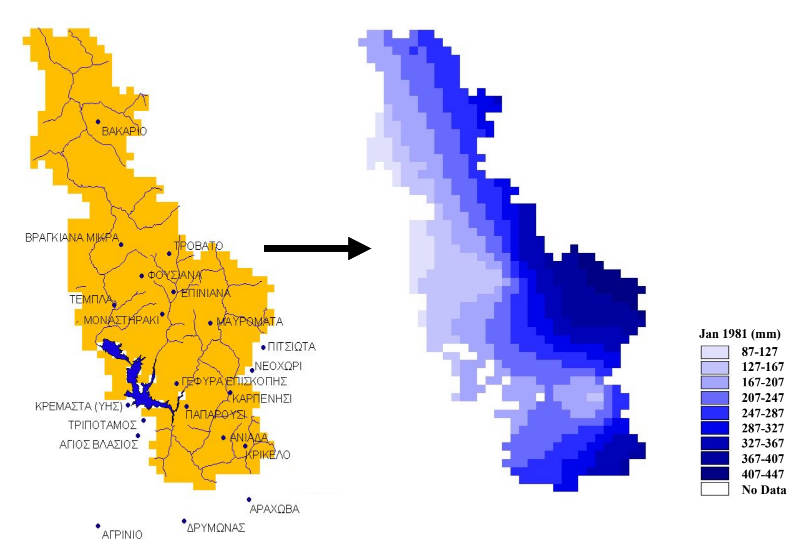


Study area

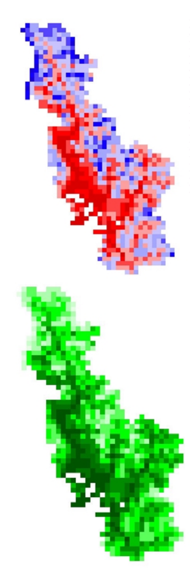


The application to the ArcView-GIS

Calculation of rainfall surfaces from point values using Kriging



Surface of monthly temperature



$T_i = T_s - c(H_{cell} - H_s)$

- T_i temperature to a specific cell
- T_S temperature to the altitude of the station
- H_{cell} cell altitude from DTM
- H_S station altitude
- c temperature gradient

Surface of potential evapotranspiration

- ✦ **Calculation of evapotranspiration:** Penman method
- ✦ **Calculation of surfaces:** Linear correlation with dependent variable the evapotranspiration (E_p) and independent variables the altitude (Z) and the mean monthly temperature (T_m)

$$E_p = -0.342Z - 0.0064T_m + 30.7$$

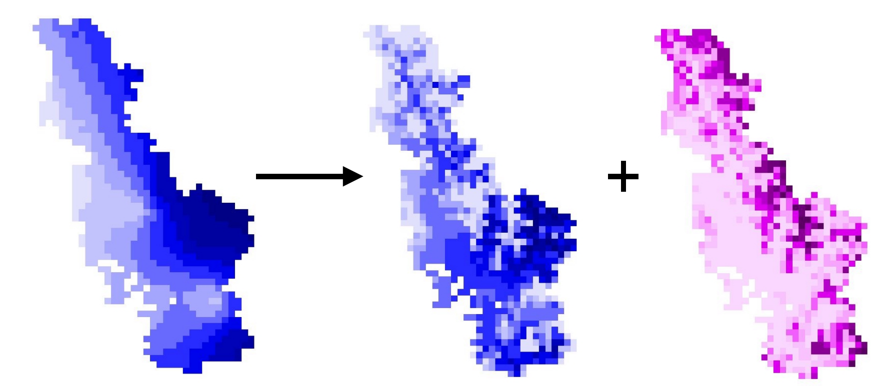
Disaggregation of precipitation (*P*) to rainfall (*R*) and snowfall (*S*)

$TD_{min} \geq 0\ ^oC \Rightarrow S=0\ \&\ R=P$

$TD_{max} < 0\ ^oC \Rightarrow S=P\ \&\ R=0$

$TD_{min} < 0\ ^oC\ \&\ TD_{max} \geq 0\ ^oC \Rightarrow S = SC_i P\ \&\ R = (1-SC_i)P$

$SC_i = T_{min}/(T_{max} - T_{min})$



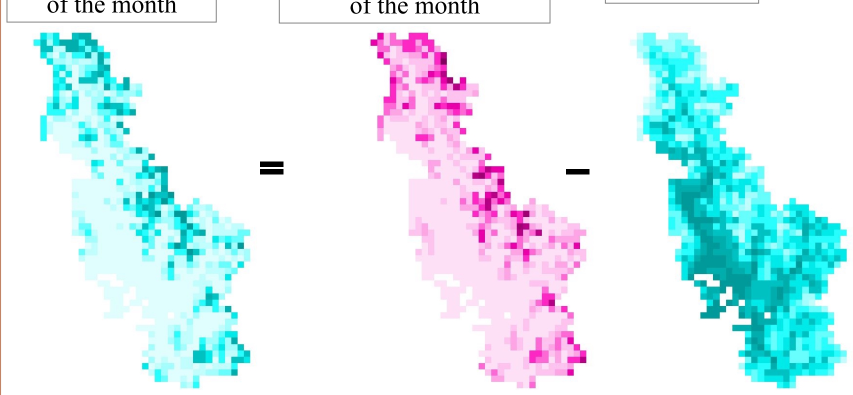
Precipitation ***P*** Rainfall ***R*** Snowfall ***S***

Surface of melted snow

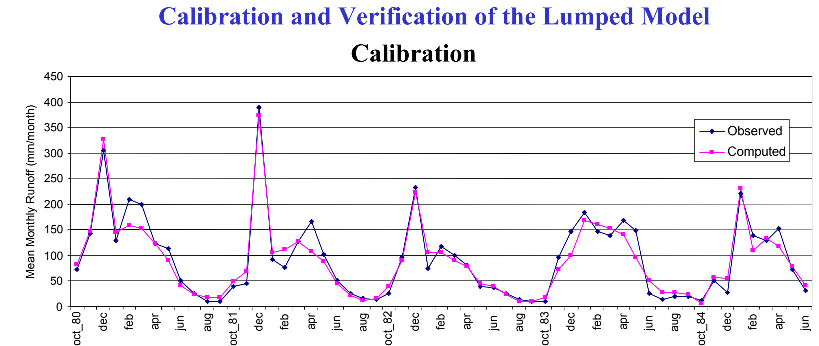
Melted snow: $SM = DDF\ T_m\ ND <= S_{start}$

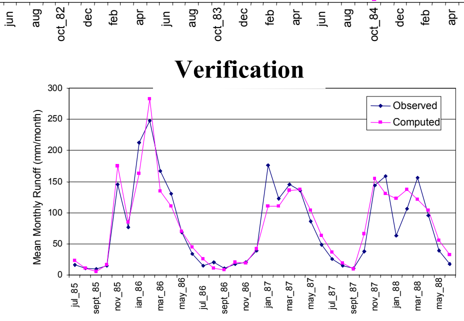
- DDF factor in mm/°C/day
- ND number of days of the specific month
- T_m grid of mean monthly temperature
- S_{start} storage at the beginning of the month

Storage at the end of the month = Storage at the beginning of the month − Snow melted



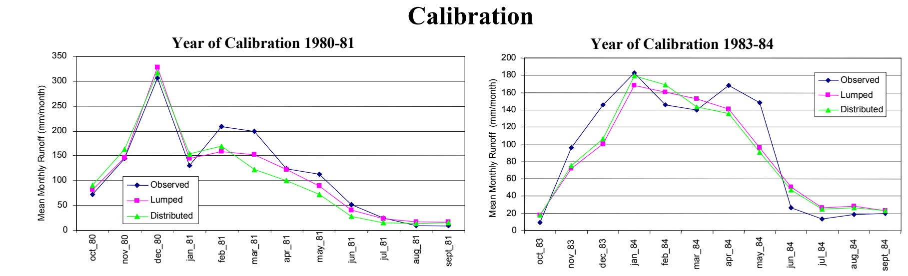
Calibration and Verification of the Lumped Model

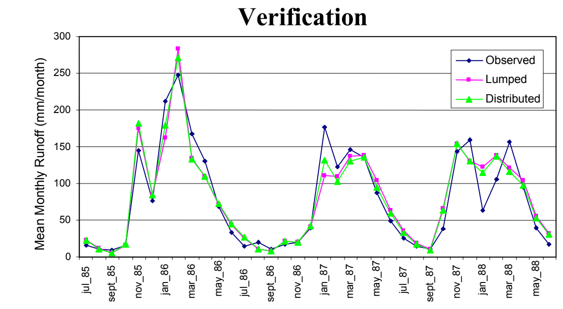




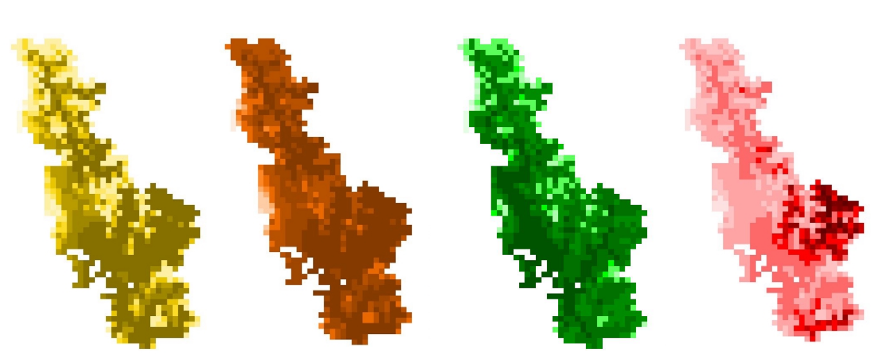
ν=0.218
κ=0.087
λ=0.069
K=154 mm

Calibration and Verification of the Distributed Model



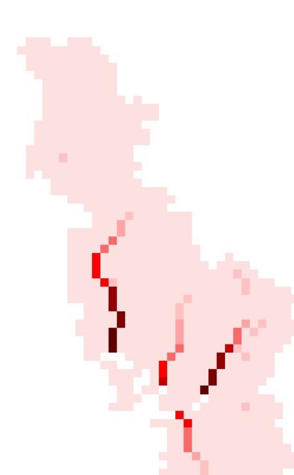


Output variable's surfaces



Storage of soil moisture reservoir, ***S*** | Storage of ground water reservoir, ***G*** | Real evapotranspiration, **RE** | Total runoff, ***Q***

Surface of accumulated runoff



Application of ArcView's standard functions for the calculation of:
- ★ Flow direction grid
- ★ Flow accumulation grid

Conclusions

- ★ A simple distributed water balance model was developed in a GIS environment, which simulates the hydrological processes using a monthly time step. The input is hydrometeorological and geographical data and the output is spatial data of runoff, evapotranspiration and water storage in different ground levels.
- ★ The model, due to its distributed character and the GIS environment, allows the calculation of the spatial distribution of the output variables. Furthermore, the output variables integration gives the monthly runoff along the rivers.
- ★ The model was calibrated using runoff values available at the basin outlet. The comparison between the observed and computed values (both for calibration and verification), shows a very satisfactory performance of the model.
- ★ Grid management in ARCVIEW-GIS was satisfactory despite the large number of created grids (more than 2000 grids were created for the application's needs).

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