
Simple water balance model using a Geographical Information System

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Topics of the presentation

★ Water balance model

★ The application to GIS

★ Calibration-verification

★ Conclusions

SIMPLE WATER BALANCE MODEL USING A GEOGRAPHICAL INFORMATION SYSTEM
 26th General Assembly of the European Geophysical Society, Nice-France, 25-30 March 2001
 Session: *Water Resources Engineering, Hydrological Mapping (HSC11)*
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<p>Abstract</p> <p>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 and storage in different conceptual reservoirs, runoff) are given in distributed format in grids with a cell size of 4 square kilometers. Successive transformations of precipitations 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 the simplicity and paucity of parameters the model yields a very satisfactory reproduction of measured discharge also providing accumulated runoff to any location of the river network, by implementing routines of a Geographical Information System.</p> <p>Study area: Acheloos water basin upstream of the Keamata dam site (area 3424 km²), Western Greece Data periods: October 1980 - June 1988 Geographical data: Digital terrain model (DTM) Sites of the hydrometeorological stations Geology of the basin Hydrographic network</p> <p>Hydrometeorological data: Precipitation Temperature Relative humidity Wind speed Sunshine duration</p> <p>GIS: ArcView Programming language: Avenue</p>	<p style="text-align: center;">Water balance model</p> <p>Input variables:</p> <ul style="list-style-type: none"> ★ Precipitation, P ★ Potential evapotranspiration, E_p ★ Average monthly temperature, TM_{avg} ★ Minimum mean daily temperature, TM_{min} ★ Maximum mean daily temperature, TM_{max} <p>Output variables:</p> <ul style="list-style-type: none"> ★ Storage of soil moisture reservoir, S ★ Storage of ground water reservoir, G ★ Actual evapotranspiration, RE ★ Total runoff, Q <p>Model parameters:</p> <ul style="list-style-type: none"> ★ Percentage of imperviousness surface, ν ★ Storage capacity of soil moisture reservoir, K ★ Recession coefficient of soil moisture, α ★ Recession coefficient of ground water, λ 	<p style="text-align: right;">Study area</p>
The application to the ArcView-GIS		
<p>Calculation of rainfall surfaces from point values using Kriging</p>	<p>Surface of monthly temperature</p> $T_i = T_c - c(H_{cell} - H_c)$ <p>T_i temperature to a specific cell T_c temperature to the altitude of the station H_{cell} cell altitude from DTM H_c station altitude c temperature gradient</p> <p>Surface of potential evapotranspiration</p> <ul style="list-style-type: none"> ★ 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) $E_p = -0.342Z - 0.0064T_m + 30.7$	<p>Disaggregation of precipitation (P) to rainfall (R) and snowfall (S)</p> $TD_{max} > 0^\circ C \Rightarrow S=0 \& R=P \quad SC_P = T_m / (T_{max} - T_{min})$ $TD_{max} < 0^\circ C \Rightarrow S=P \& R=0$ $TD_{min} < 0^\circ C \& TD_{max} > 0^\circ C \Rightarrow S = SC_P P \& R = (1-SC_P)P$ <p style="text-align: center;">Precipitation P Rainfall R Snowfall S</p>
<p>Surface of melted snow</p> $SM = DDF T_m ND \leq S_{max}$ <p>DDF factor in mm/°C/day T_m grid of mean monthly temperature ND number of days of the specific month S_{max} storage at the beginning of the month</p> <p>Storage at the end of the month = Storage at the beginning of the month - Snow melted</p>	<p>Calibration and Verification of the Lumped Model</p> <p style="text-align: center;">Calibration</p> <p style="text-align: center;">Verification</p> <p>$r=0.218$ $\alpha=0.087$ $\lambda=0.069$ $K=154 \text{ mm}$</p>	<p>Calibration and Verification of the Distributed Model</p> <p style="text-align: center;">Calibration</p> <p style="text-align: center;">Verification</p>
<p>Output variable's surfaces</p>	<p>Surface of accumulated runoff</p> <p>Application of ArcView's standard functions for the calculation of:</p> <ul style="list-style-type: none"> ★ Flow direction grid ★ Flow accumulation grid 	<p style="text-align: center;">Conclusions</p> <ul style="list-style-type: none"> ★ 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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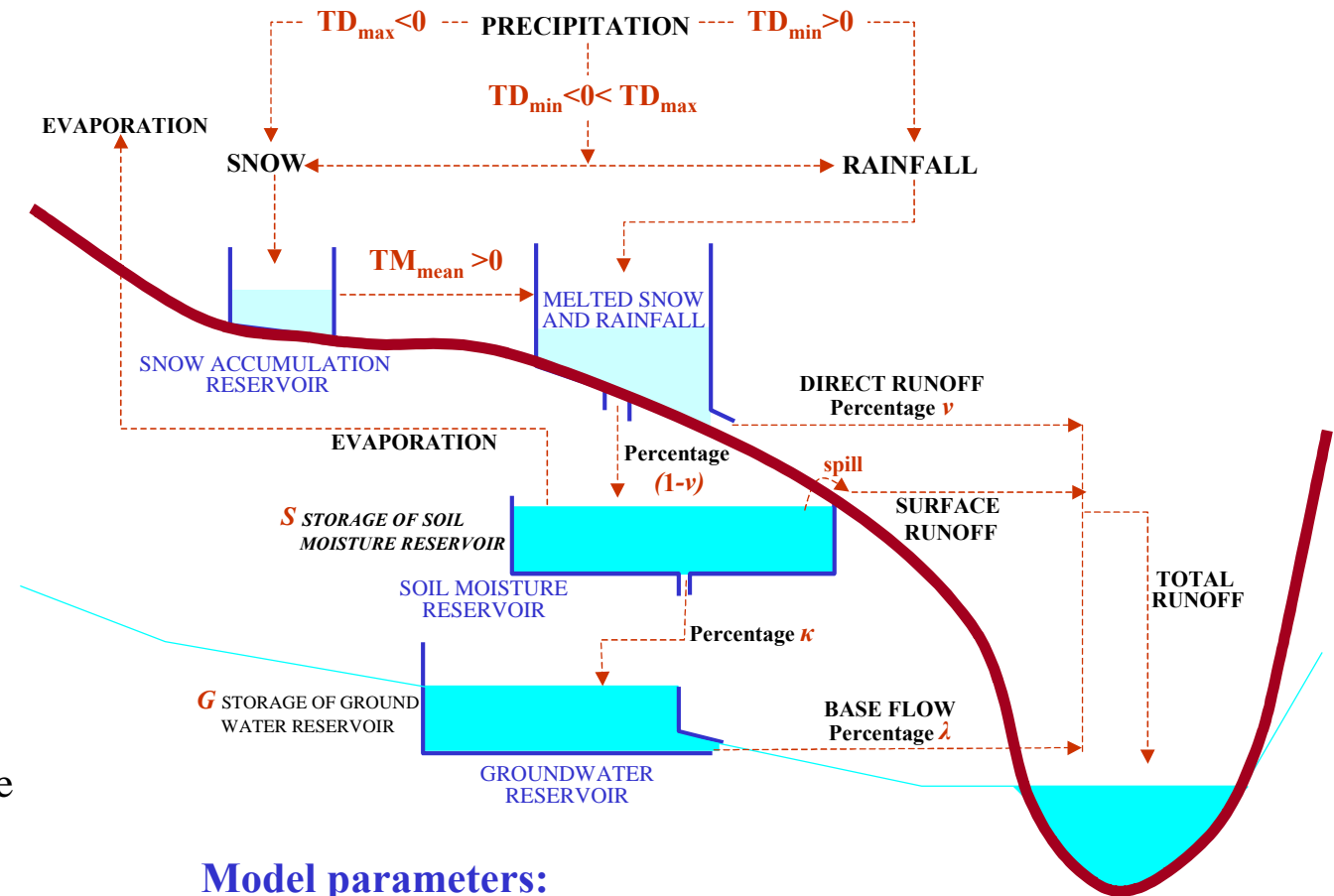
Water balance model

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, v
- ★ Storage capacity of soil moisture reservoir, K
- ★ Recession coefficient of soil moisture, κ
- ★ Recession coefficient of ground water, λ

The application to GIS

Model characteristics

Time step: monthly

Cell size: 2X2 km²

Data period:

October 1980-June 1988

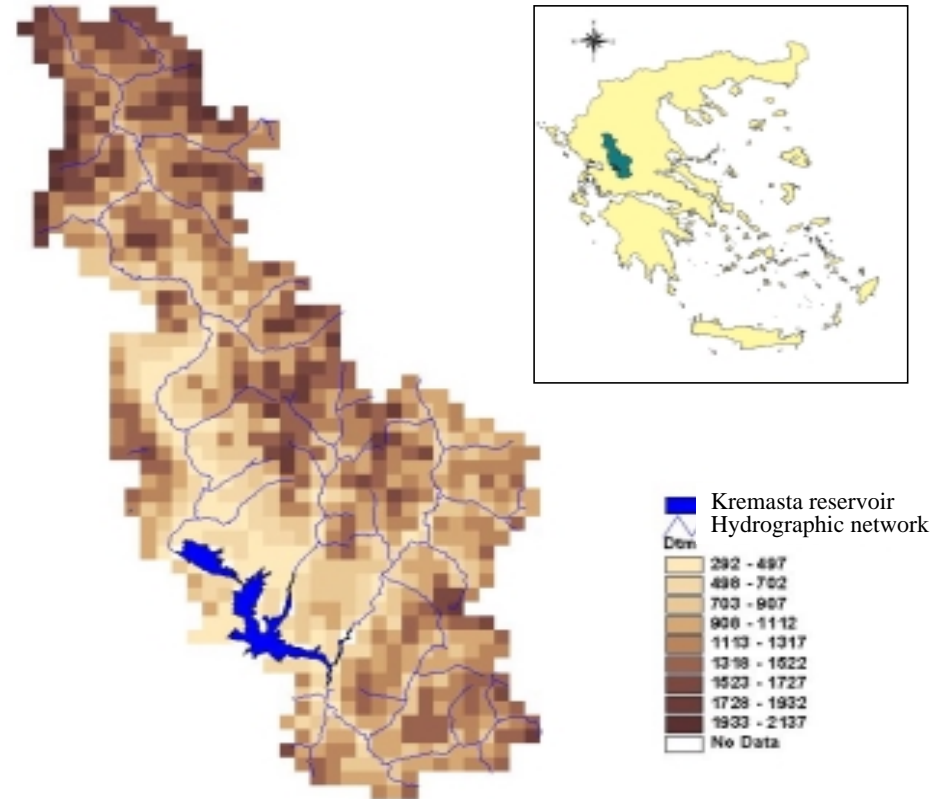
GIS: ArcView

Programming language:

Avenue

Study area

Acheloos water basin upstream of the Kremasta dam site (area 3424 km²), Western Greece



The application to GIS

(data used)

Geographical data

- Digital elevation model (DEM)
- Sites of the hydrometeorological stations
- Geology of the basin
- River network

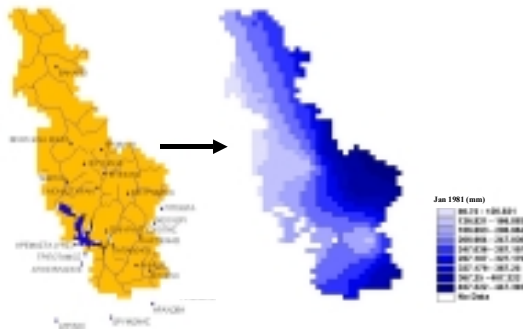
Hydrometeorological data

- Precipitation
- Temperature
- Relative humidity
- Wind speed
- Sunshine duration
- Discharge at the basin outlet

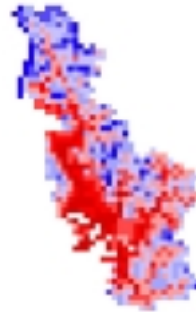
The application to GIS

Calculated surfaces

Precipitation
(from point values
using Kriging method)



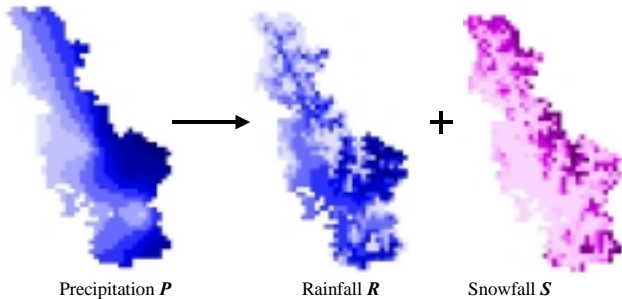
Temperature
(using points values, cell
altitude and temperature
gradient)



Potential evapotranspiration
(using points values cell
altitude and temperature)

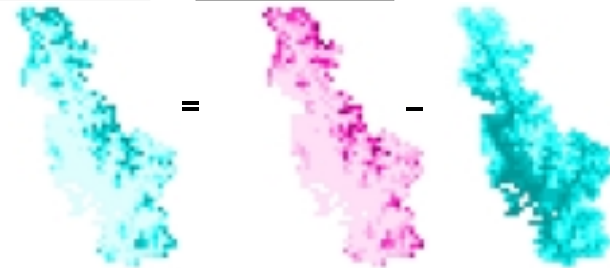


Dissaggregation of precipitation
(to rainfall and snowfall using minimum
and maximum daily temperature)



Melted snow
(using temperature and storage)

$$\text{Storage at the end of the month} = \text{Storage at the beginning of the month} - \text{Snow melted}$$



The application to GIS

Output variable's surfaces

**Storage of soil
moisture reservoir**



**Storage of ground
water reservoir**



**Real
evapotranspiration**



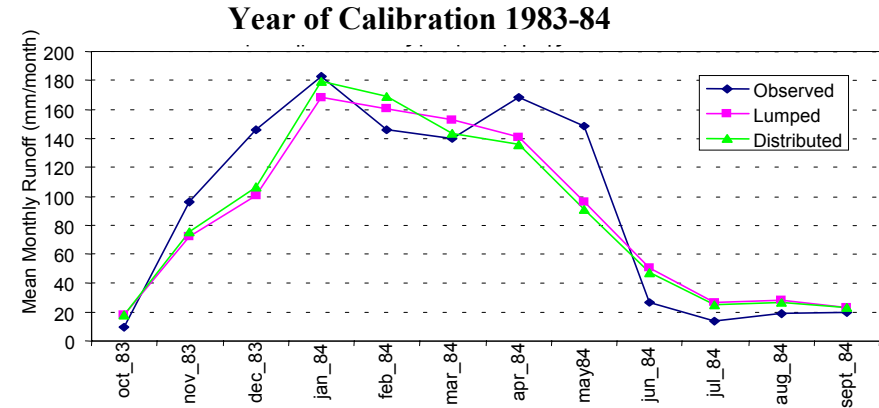
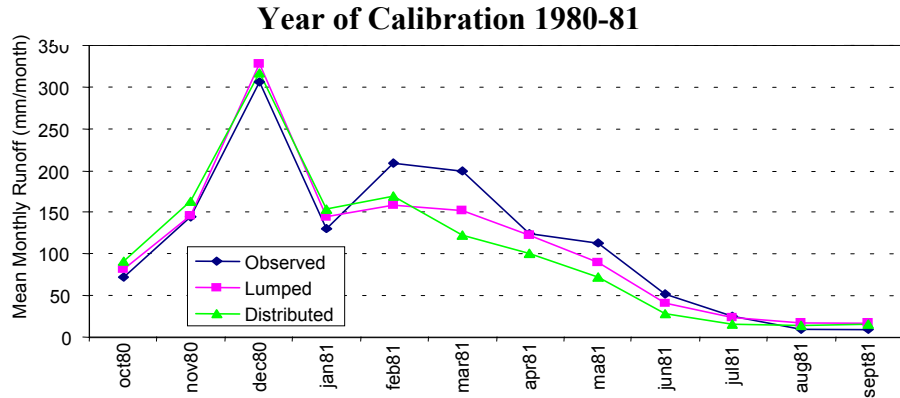
Total runoff



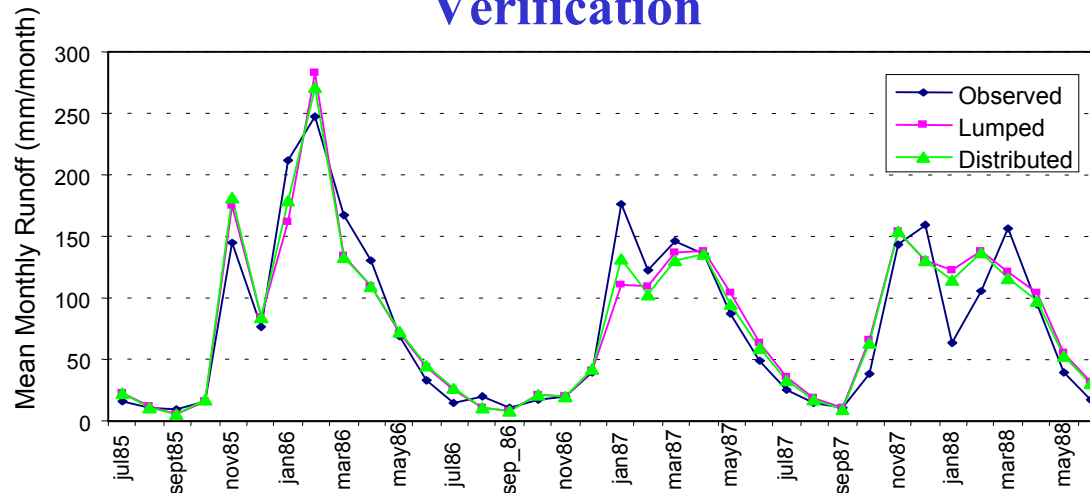
Accumulated runoff

Calibration and verification of the distributed model

Calibration



Verification



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).