European Procedures for Flood Frequency Estimation –
FLOODFREQ COST ACTION ES0901

3rd Management Committee Meeting, Prague, 28-29 October 2010

WG3: Use of rainfall-runoff models for flood frequency estimation

Review of existing simulation based flood-frequency frameworks in Greece

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Introduction

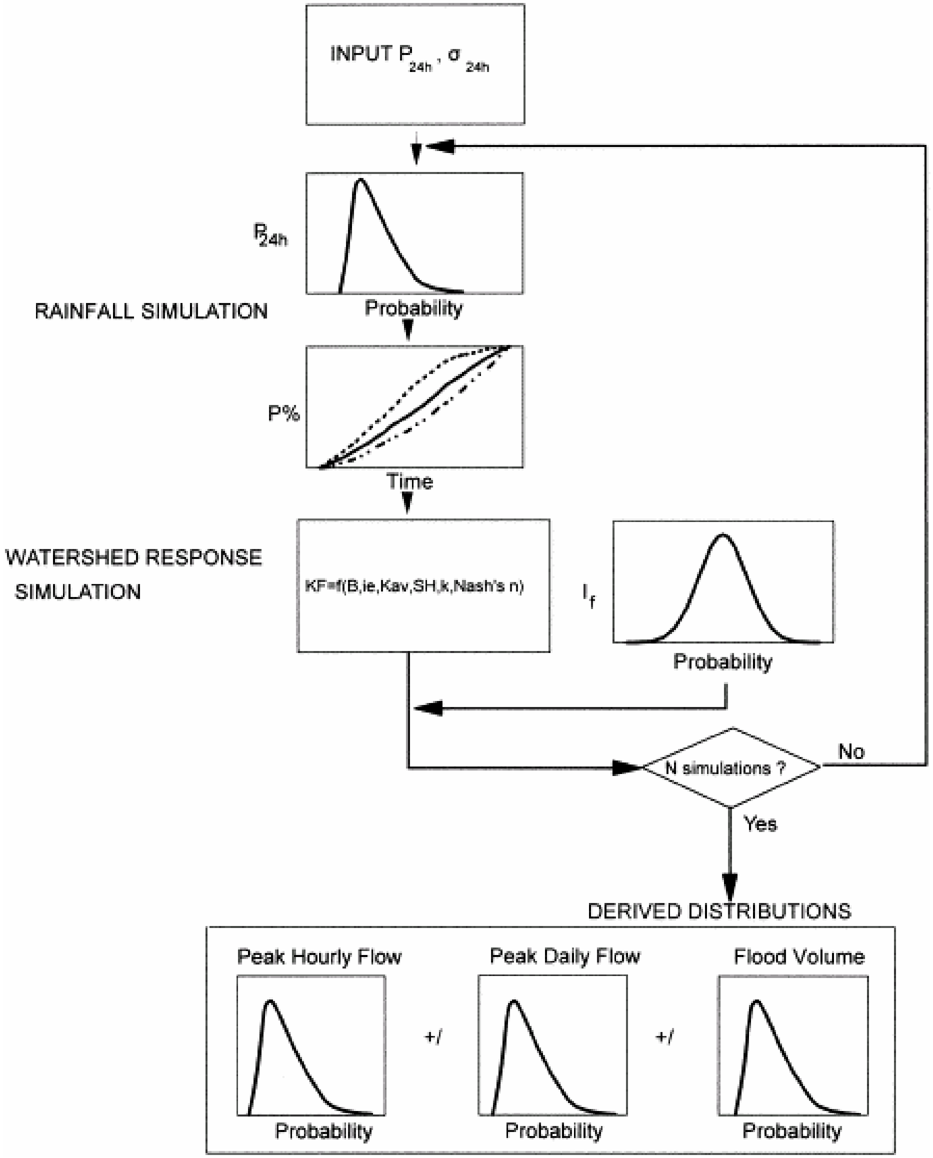
- **Engineering studies in Greece utilize rather outdated or simplistic rules-of-thumb**
  - Rational method (design of urban drainage networks, road drainage systems and flood-protection projects in rural basins of small and medium scale, where return periods of 5 to 50 years are assigned).
  - Application of Unit Hydrograph (UH) theory in some engineering studies.
  - Event-based models, such as the HEC-HMS and HEC-RAS, are less often used, for the hydrologic design of large projects, such as spillways, bridges, etc., which are designed for higher return periods.
  - There is no experience with continuous simulation tools and stochastic models, in practical applications.
- **Research approaches for flood modelling (UTH, NTUA)**
  - Event-based models for flood frequency analysis (Loukas, 2002);
  - Continuous flood modelling and flood frequency assessment, for gauged and ungauded watersheds (Loukas and Vasiliades, 2003);
  - Stochastic rainfall models coupled with continuous hydrological models (Efstratiadis *et al.*, 2009; Efstratiadis and Papalexiou, 2010).

Flood frequency estimation by a derived distribution procedure for ungauged basins

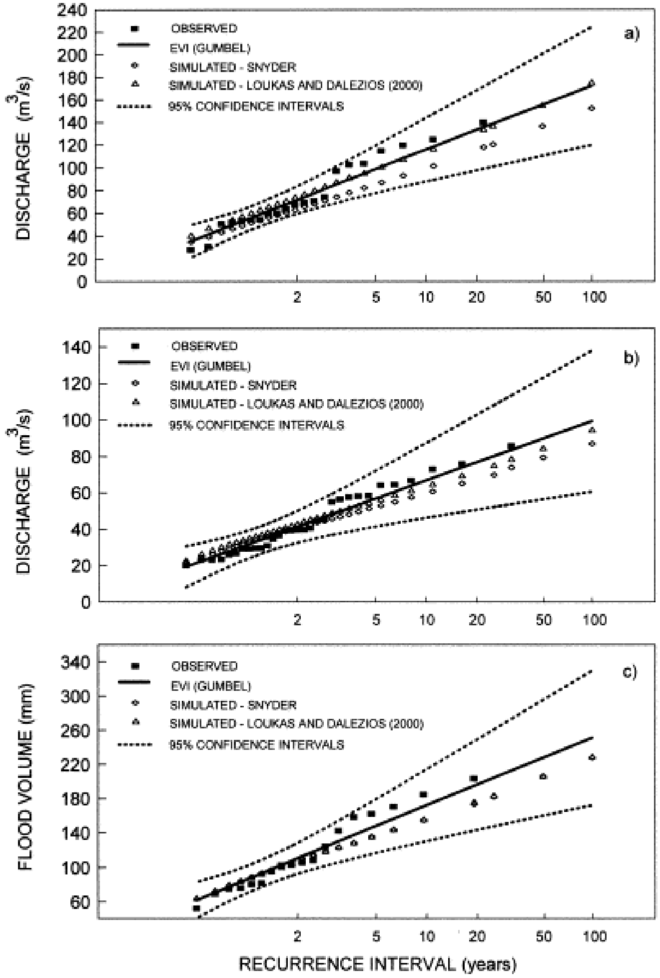
- **Stochastic rainfall generation model**
  - The 24-hour storm can be used as the representative storm in absence of more detailed observed data
  - Storm depth is assumed to follow the Extreme Value type I (EVI) distribution
- **Rainfall-runoff watershed model**
  - Event-based model, which uses a linear reservoir routing technique and simulates the fast runoff with a series of cascading linear reservoirs and the slow runoff with one large reservoir
- **Data requirements**
  - The method requires information about hydrology and topography of the watershed area, estimated from data measured in the field or estimated from rainfall and topographical maps.

The derived distribution procedure

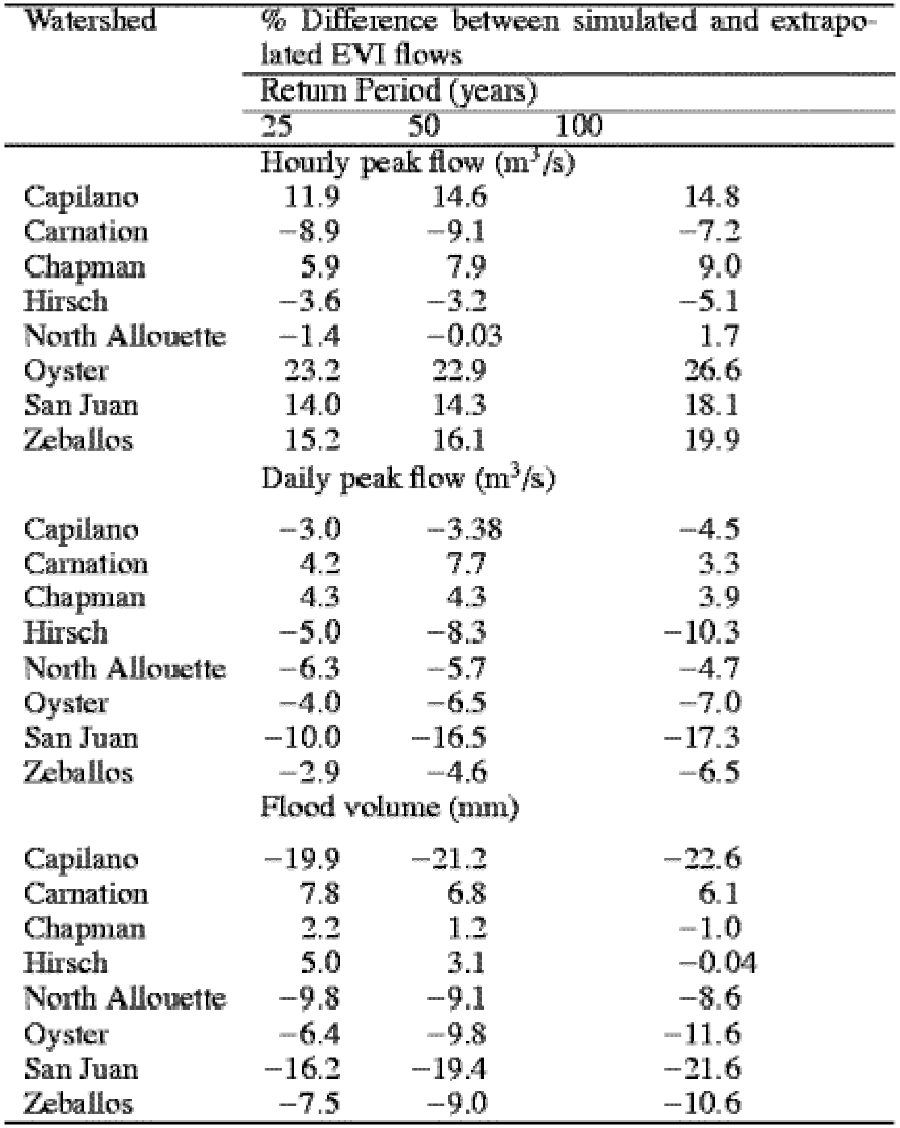
- Employs a Monte-Carlo simulation for estimating:
  - peak hourly discharge;
  - peak daily discharge;
  - peak flood volume.
- The procedure was tested to eighth gauged forested coastal British Columbia watersheds.
- The watersheds should:
  - be mainly rain-fed watersheds;
  - have natural flow, with no man-made storage impoundment;
  - have negligible natural lake storage;
  - have long enough flow records to allow for statistical analysis.



Results from event-based modelling



Flood frequency results for North Allouette River basin: (a) hourly flows, (b) daily flows, (c) flood volume



Watershed	% Difference between simulated and extrapolated EVI flows		
	Return Period (years)		
	25	50	100
	Hourly peak flow (m^3/s)		
Capilano	11.9	14.6	14.8
Carnation	−8.9	−9.1	−7.2
Chapman	5.9	7.9	9.0
Hirsch	−3.6	−3.2	−5.1
North Allouette	−1.4	−0.03	1.7
Oyster	23.2	22.9	26.6
San Juan	14.0	14.3	18.1
Zeballos	15.2	16.1	19.9
	Daily peak flow (m^3/s)		
Capilano	−3.0	−3.38	−4.5
Carnation	4.2	7.7	3.3
Chapman	4.3	4.3	3.9
Hirsch	−5.0	−8.3	−10.3
North Allouette	−6.3	−5.7	−4.7
Oyster	−4.0	−6.5	−7.0
San Juan	−10.0	−16.5	−17.3
Zeballos	−2.9	−4.6	−6.5
	Flood volume (mm)		
Capilano	−19.9	−21.2	−22.6
Carnation	7.8	6.8	6.1
Chapman	2.2	1.2	−1.0
Hirsch	5.0	3.1	−0.04
North Allouette	−9.8	−9.1	−8.6
Oyster	−6.4	−9.8	−11.6
San Juan	−16.2	−19.4	−21.6
Zeballos	−7.5	−9.0	−10.6

The UBC model for continuous simulation

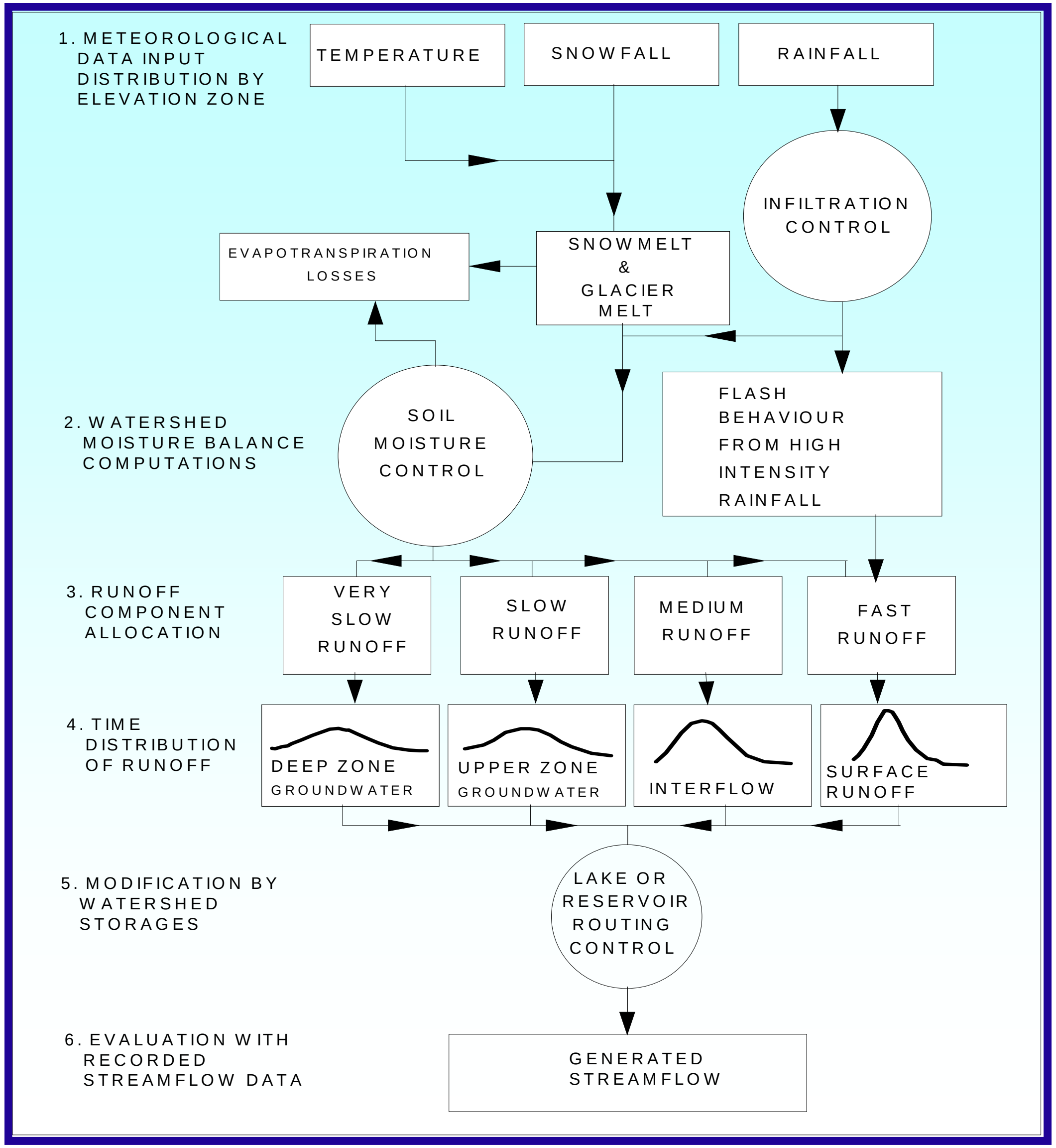
- Use of the UBC watershed model for streamflow modelling and flood frequency estimation.
- Regional application of the UBC model for ungauged watersheds
  - Use of a universal set of parameters for water allocation and flow routing, and the precipitation gradients estimated from annual meteorological data as well as information on the distribution of orographic precipitation
  - Typical EV analysis for assessing flood frequency
- Rainfall-runoff watershed model
- Application of the UBC model for poorly-gauged watersheds
  - Coupling the regional application of the UBC watershed model with ANN's for runoff simulation with limited streamflow measurements
  - Typical EV analysis for assessing flood frequency
- Application to four mountainous watersheds having various climatic, physiographic and hydrological characteristics.

The UBC watershed model

- The model conceptualizes the watershed as a number of elevation bands.
- Model inputs are daily precipitation and minimum and maximum daily temperature, from a number of meteorological stations.
- The model distributes the input data over the elevation range of the watershed, using precipitation gradients and temperature lapse rates.
- A simplified energy balance algorithm is used to compute the accumulation and melting of the snowpack.
- The runoff from rainfall, snowmelt and glacier melt is distributed into four runoff components, is achieved with a soil moisture control mechanism.
- The linear reservoir routing technique is used for the calculation of each runoff component.

Flowchart of the UBC model

- The model distributes the rainfall and snowmelt runoff into the following components:
  - rainfall fastflow;
  - snowmelt fastflow;
  - rainfall interflow;
  - snowmelt interflow;
  - upper zone groundwater;
  - deep zone groundwater;
  - glacial melt runoff (if exists).



1. METEOROLOGICAL DATA INPUT DISTRIBUTION BY ELEVATION ZONE

TEMPERATURE

SNOWFALL

RAINFALL

INFILTRATION CONTROL

EVAPOTRANSPIRATION LOSSES

SNOWMELT & GLACIER MELT

2. WATERSHED MOISTURE BALANCE COMPUTATIONS

SOIL MOISTURE CONTROL

FLASH BEHAVIOUR FROM HIGH INTENSITY RAINFALL

3. RUNOFF COMPONENT ALLOCATION

VERY SLOW RUNOFF

SLOW RUNOFF

MEDIUM RUNOFF

FAST RUNOFF

4. TIME DISTRIBUTION OF RUNOFF

DEEP ZONE GROUNDWATER

UPPER ZONE GROUNDWATER

INTERFLOW

SURFACE RUNOFF

5. MODIFICATION BY WATERSHED STORAGES

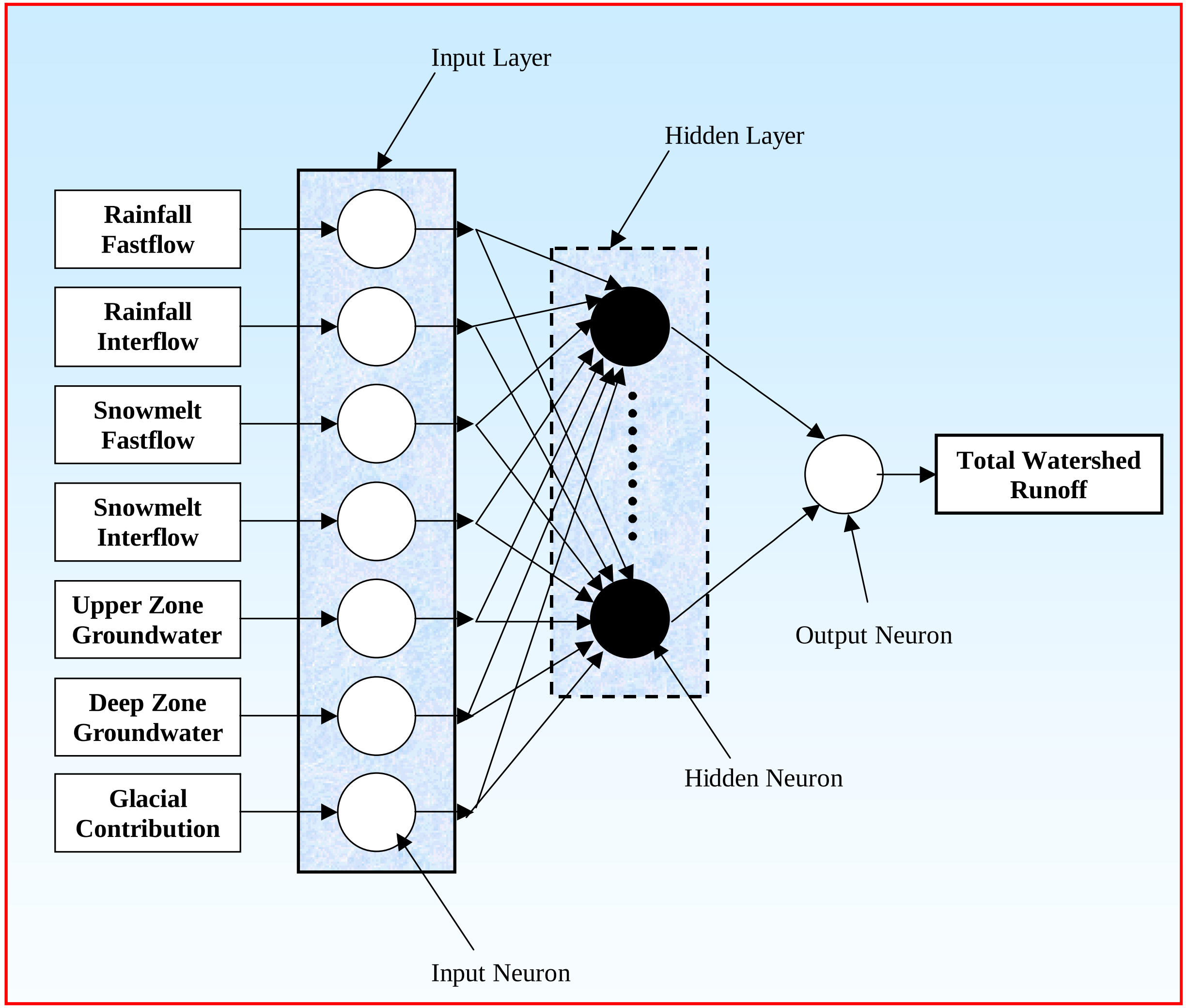
LAKE OR RESERVOIR ROUTING CONTROL

6. EVALUATION WITH RECORDED STREAMFLOW DATA

GENERATED STREAMFLOW

Coupling of regional UBC model outputs with ANNs

- The seven runoff components are used as input nodes of ANNs (input layer).
- The watershed runoff is the output node of ANNs.
- The methodology is applicable to watersheds with limited streamflow data.



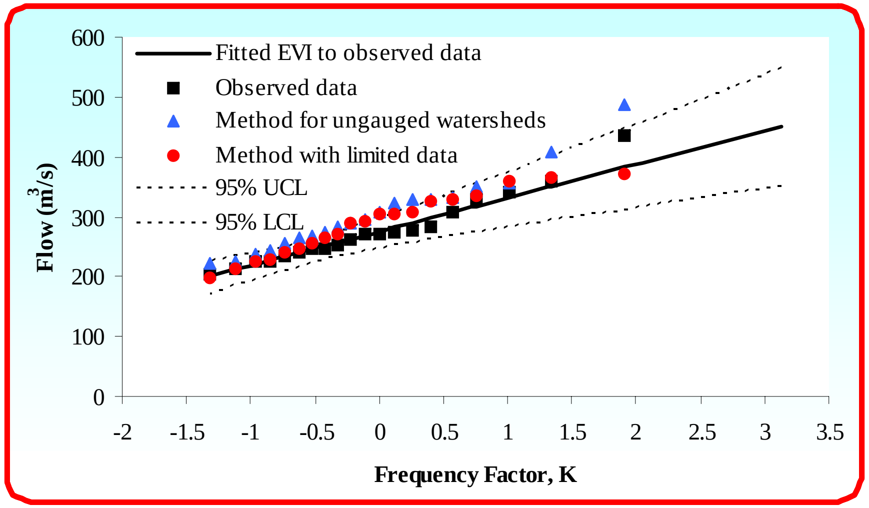
Results on model performance

- Statistics for the two proposed methodologies for ungauged watersheds and watersheds with limited data for streamflow simulation

Hydrologic Period	**Methodology for ungauged watersheds**			**Methodology for watersheds with limited data**		
	Eff.	R^2	DV(%)	Eff.	R^2	DV(%)
Upper Campbell Watershed						
Period 1983-86	0.72	0.73	-7.80	0.82	0.82	-0.69
Period 1986-90	0.68	0.68	-3.93	0.68	0.70	0.47
Illecillewaet Watershed						
Period 1970-73	0.89	0.92	12.03	0.97	0.97	-0.04
Period 1973-90	0.83	0.91	15.09	0.90	0.91	2.11
Yermasoyia Watershed						
Period 1986-89	0.78	0.78	14.94	0.91	0.91	2.71
Period 1989-97	0.69	0.74	8.91	0.80	0.81	-4.15
Astore Watershed						
Period 1979-82	0.76	0.81	-6.15	0.94	0.94	-1.40
Period 1982-88	0.59	0.64	-7.87	0.79	0.79	-3.05

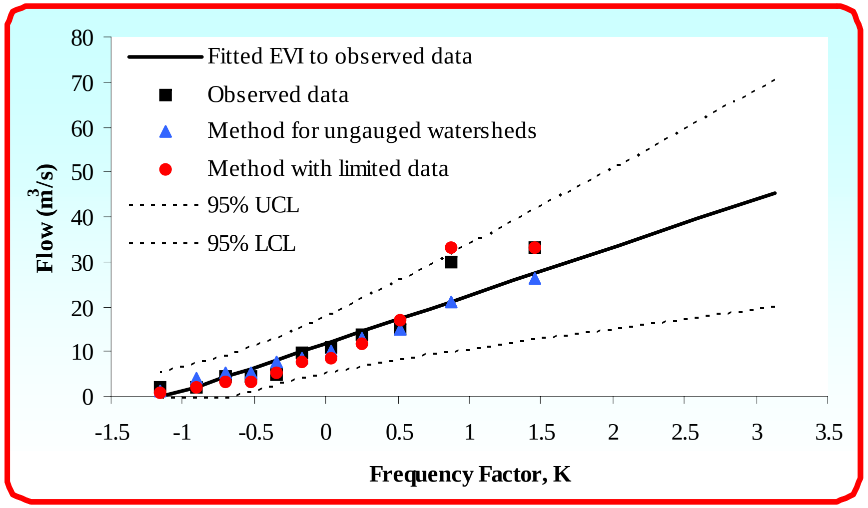
Flood frequency estimation

Illecillewaet watershed, Canada



Return Period (Years)	Fitted EVI Observed data (m^3/s)	Fitted EVI Ungauged watersheds (m^3/s)	Fitted EVI Watersheds with limited data (m^3/s)
25	390.4	435.6	392.9
50	421.3	470.8	421.4
100	452	505.8	449.7

Yermasoyia watershed, Cyprus



Return Period (Years)	Fitted EVI Observed data (m^3/s)	Fitted EVI Ungauged watersheds (m^3/s)	Fitted EVI Watersheds with limited data (m^3/s)
25	33.7	26.2	35.2
50	39.6	30.3	41.6
100	45.4	34.5	47.9

Remarks on using the UBC model for continuous simulation

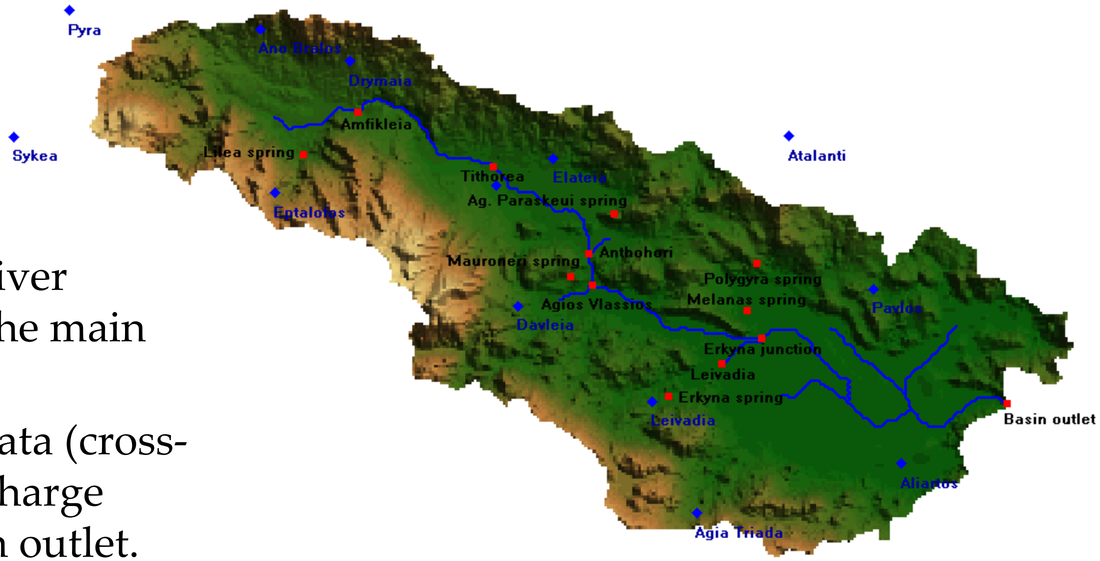
- The regional application of the UBC model should be applied with caution in watersheds with different runoff producing mechanisms.
- The estimation of the model parameters requires good knowledge of the study watershed (area, elevation bands, vegetation coverage, soils, etc.) and enough meteorological data to estimate the precipitation distribution over the elevation range of the watershed or information about the orographic precipitation gradients across the watershed.
- Given that runoff data are available, the coupling of the UBC regional model with ANNs provides a good alternative to the classical application (UBC calibration and validation), without the need of optimizing UBC model parameters. This method is proposed for watersheds having limited streamflow data for successful streamflow modelling and estimation of flood frequency.

Coupling of a stochastic rainfall model with the HYDROGEIOS model for flood risk assessment

- Why a stochastic rainfall model?
  - The conventional methodology based on the use of “design storms” fails to properly represent the variability of precipitation, given that the temporal and spatial correlations of the historical records are not represented.
  - A multivariate stochastic model is essential to preserve the key statistical properties of rainfall (including auto and cross-correlations, probability dry).
- Why a continuous simulation model?
  - Event-based approaches do not interpret flood risk as joint probabilities of all hydrological variables that interrelate in runoff generation (e.g. stream-aquifer interactions, soil moisture accounting).
  - Calibration against normally few flood events, which is at least questionable.
- Why a conjunctive model?
  - The contribution of baseflow may be significant (karst areas).
  - In modified hydrosystems, the existence of human interventions (hydraulic works and abstractions) drastically affect the hydrological cycle.

Study area: Boeoticos Kephisos basin

- Drains a formerly closed area of 1850 km^2, whose flows are conducted to the neighbouring Lake Yliki (major reservoir for the Athens water supply).
- Due to the dominance of highly-permeable geologic formations, almost half of runoff derives from karst springs, which rapidly contribute to the streamflow, in contrast to the unusually low contribution of flood runoff.
- Due to the combined abstractions from surface and groundwater recourses and the existence of an artificial drainage network in the lower part of the basin (where slopes are noticeably low), the system is heavily modified.
- Data for flood modelling
  - Point rainfall data at 13 stations;
  - Mean daily discharge series at the basin outlet;
  - Sparse flow data along the river course and downstream of the main karst springs;
  - Lack of detailed hydraulic data (cross-section geometry, stage-discharge curves), apart from the basin outlet.

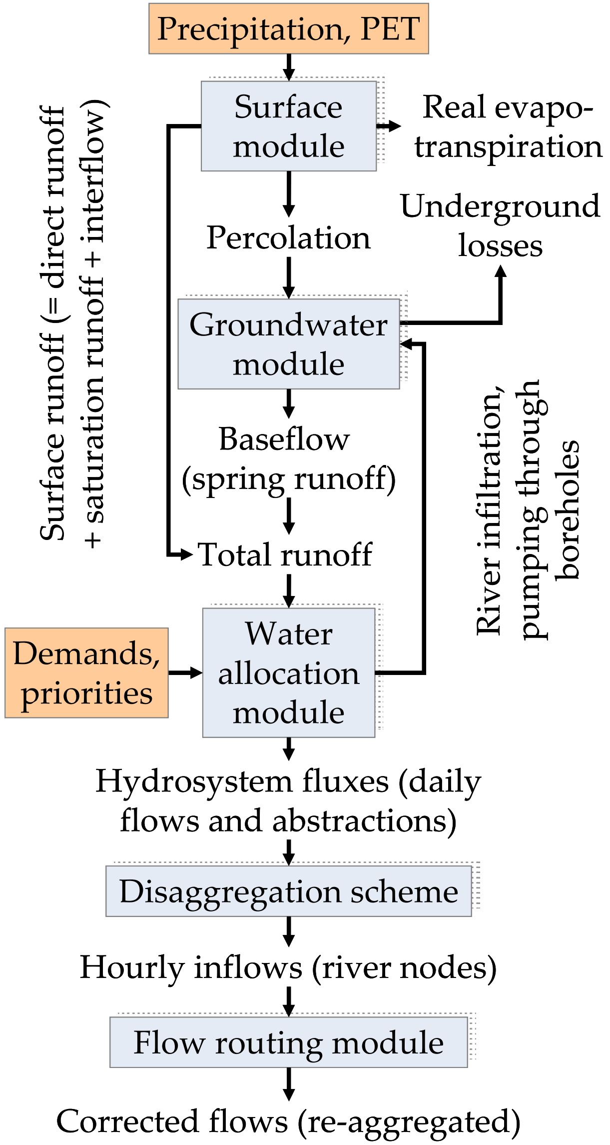


Generation of synthetic daily rainfall

- A multivariate stochastic rainfall model is developed that reproduces:
  - the seasonal (monthly) variation;
  - the probability dry;
  - the mean and the variance of the marginal distribution,
  - the power-type asymptotic tail of the distribution, which is strongly related to frequent occurrences of extreme events;
  - the lag-1 autocorrelations;
  - the lag-0 and lag-1 cross-correlations among the stations.
- The methodological framework comprises:
  - a Multivariate Auto Regressive (MAR) model to generate normal multivariate cyclostationary random variables, to preserve the auto- and cross-correlation structure as close as possible;
  - a general technique for transforming the normal variables to variables exhibiting the rainfall characteristics at each station and month.
- The model was used for generating 1000 years of point daily rainfall at 13 stations, next aggregated to the appropriate spatial scale (sub-basin).

The HYDROGEIOS modelling framework

- **Surface hydrology module (daily time step)**
  - Semi-distributed schematization;
  - Conceptualization through three interconnected tanks;
  - Inputs: daily rainfall and PET, varying per sub-basin;
  - Parameters: 7 per hydrological response unit;
  - Outputs: evapotranspiration, percolation and runoff.
- **Groundwater module (daily time step)**
  - Finite-volume approach, aquifer discretization to a limited number of polygonal cells of flexible shape;
  - Darcian representation of flow field;
  - Stress data: percolation, infiltration, pumping;
- **Water allocation module (daily time step)**
  - Representation of water uses and main hydraulic structures;
  - Step-by-step estimation of unknown flows and abstractions through a linear optimization approach.
- **Flow routing module (hourly time step)**
  - Construction of hourly-resolved inflow hydrographs, through an empirical disaggregation scheme;
  - Flow routing (kinematic-wave or Muskingum model).



Precipitation, PET

Surface module

Real evapo-transpiration

Surface runoff (= direct runoff + saturation runoff + interflow)

Percolation

Underground losses

Groundwater module

Baseflow (spring runoff)

Total runoff

River infiltration, pumping through boreholes

Demands, priorities

Water allocation module

Hydrosystem fluxes (daily flows and abstractions)

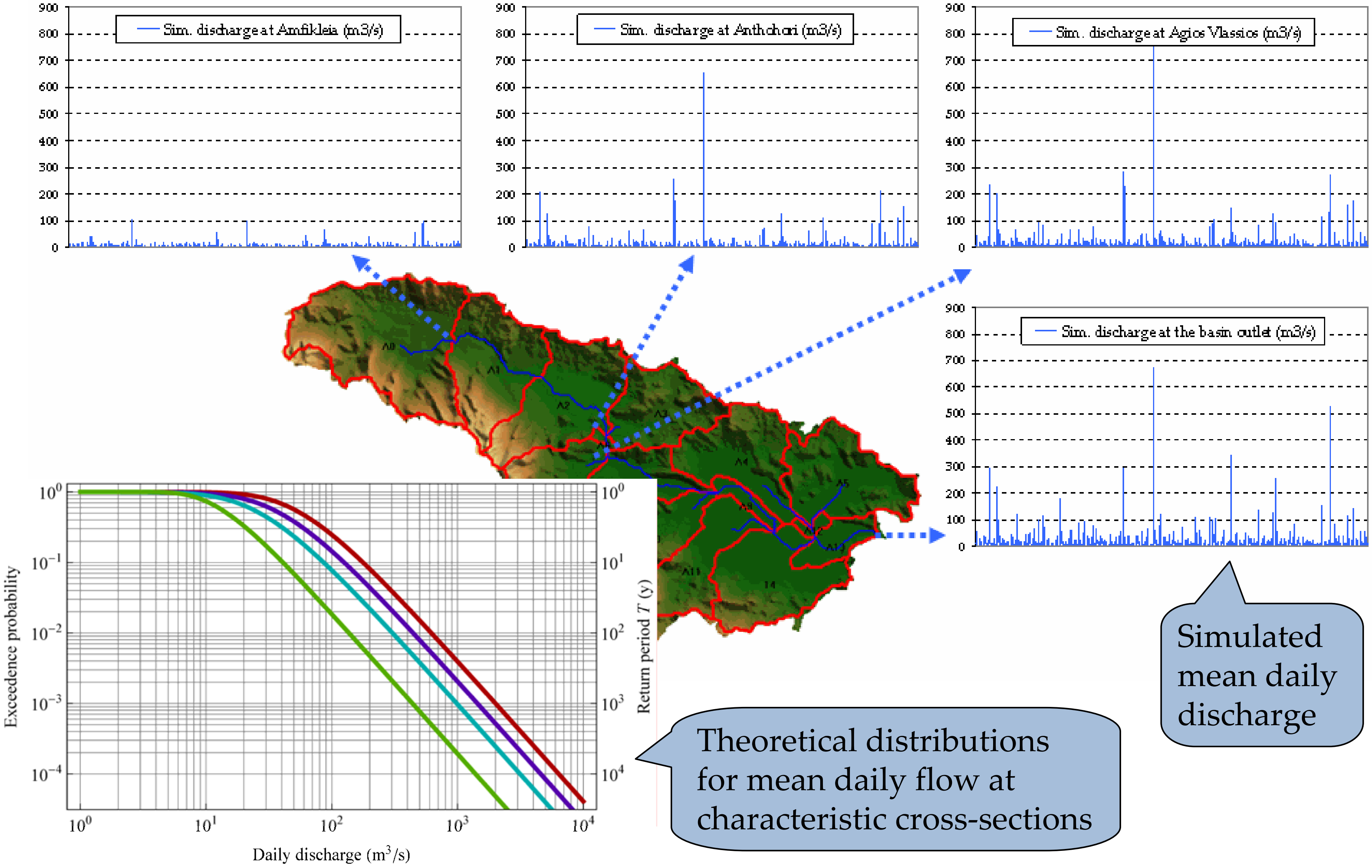
Disaggregation scheme

Hourly inflows (river nodes)

Flow routing module

Corrected flows (re-aggregated)

Evaluation of flood risk through simulation



Simulated mean daily discharge

Theoretical distributions for mean daily flow at characteristic cross-sections

Relevant publications

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