International conference: Advanced methods for flood estimation in a variable and changing environment

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Investigation of hydrological design practices based on historical flood events in an experimental basin of Greece (Lykorema, Penteli)

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Motivation and objectives

- Motivation: Investigation of typical engineering practices for flood design in ungauged basins, adapted to the hydroclimatic and geomorphological characteristics of the small-scale Greek basins, with ephemeral flow
- Objectives: Evaluation and, if possible, improvement of the combined procedure based on the SCS-CN model and the synthetic unit hydrograph (SUH) approach, for the computation of design flood hydrographs
- Study area: Experimental basin of Lykorema stream, close to Athens (15.2 km^2)
- Methodology: Back-analysis of observed storm and flood events, following the SCS-CN & SUH procedure

Typical procedure for the derivation of design hydrographs in ungauged basins

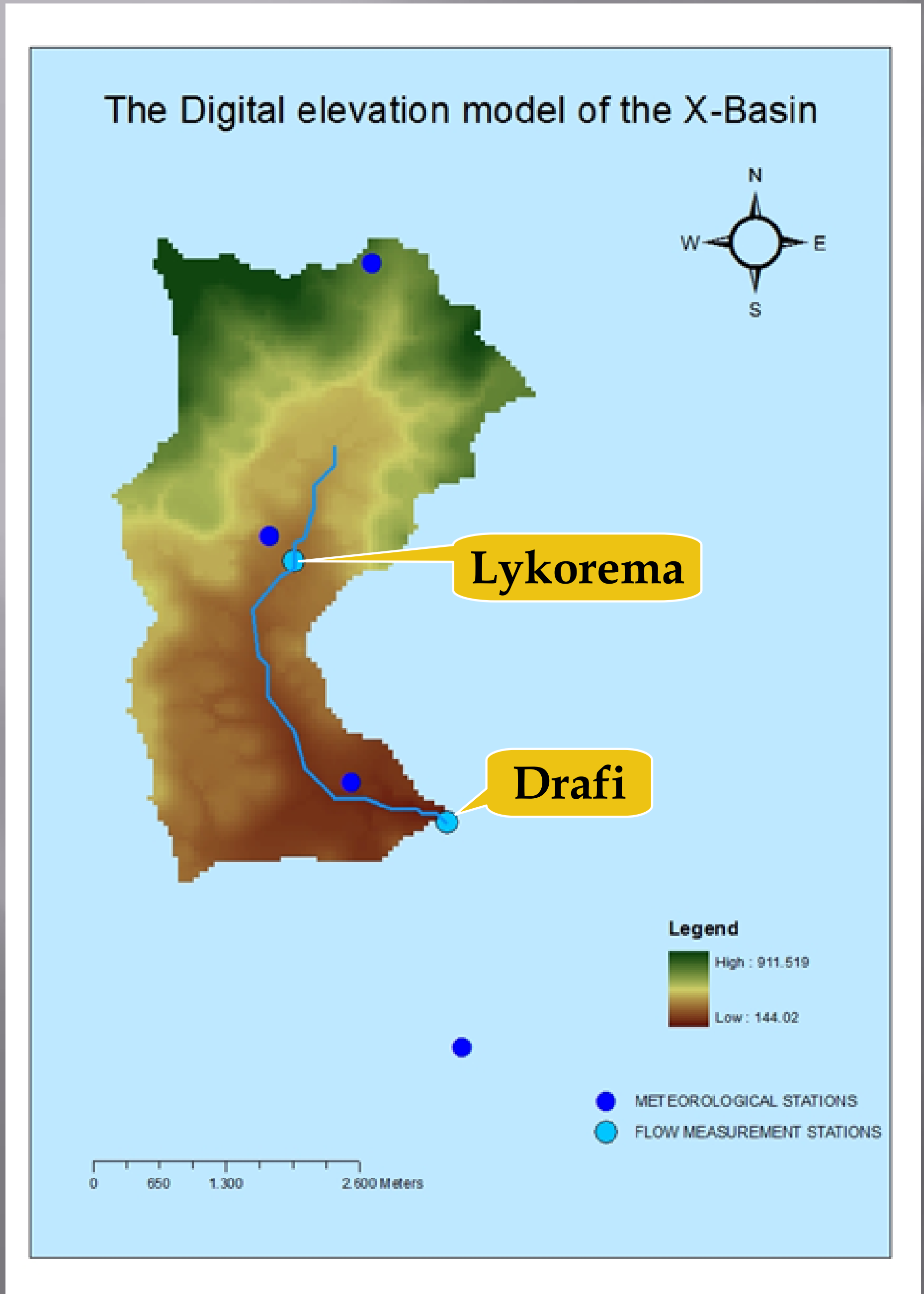
- Formulation of design storm
  - Estimation of rainfall depths through IDF analysis
  - Temporal distribution of rainfall (e.g. building block method)
- Estimation of "effective" rainfall (direct runoff)
  - Typically using the SCS-CN method
  - Requires the estimation of two parameters, i.e. the potential maximum soil moisture retention and the initial abstraction ratio
  - Assumptions are also made for initial soil moisture conditions
- Computation of flood hydrograph at the basin outlet
  - Typically using a synthetic unit hydrograph (SUH)
  - The shape of the UH depends on basin characteristics, the most important of which is the time of concentration (t_c)
  - t_c is estimated using empirical formulas (e.g. Giandotti)

Preliminary questions

- How realistic are the assumptions of the flood modeling procedure, based on the SCS-CN & SUH approach?
- How suitable are the existing empirical formulas for the estimation of the various model parameters?
- Which of them are, in fact, constants and which should be regarded as variables?
- Which aspects of the whole methodology should be revised, in order to be consistent with the peculiarities of the Greek basins?

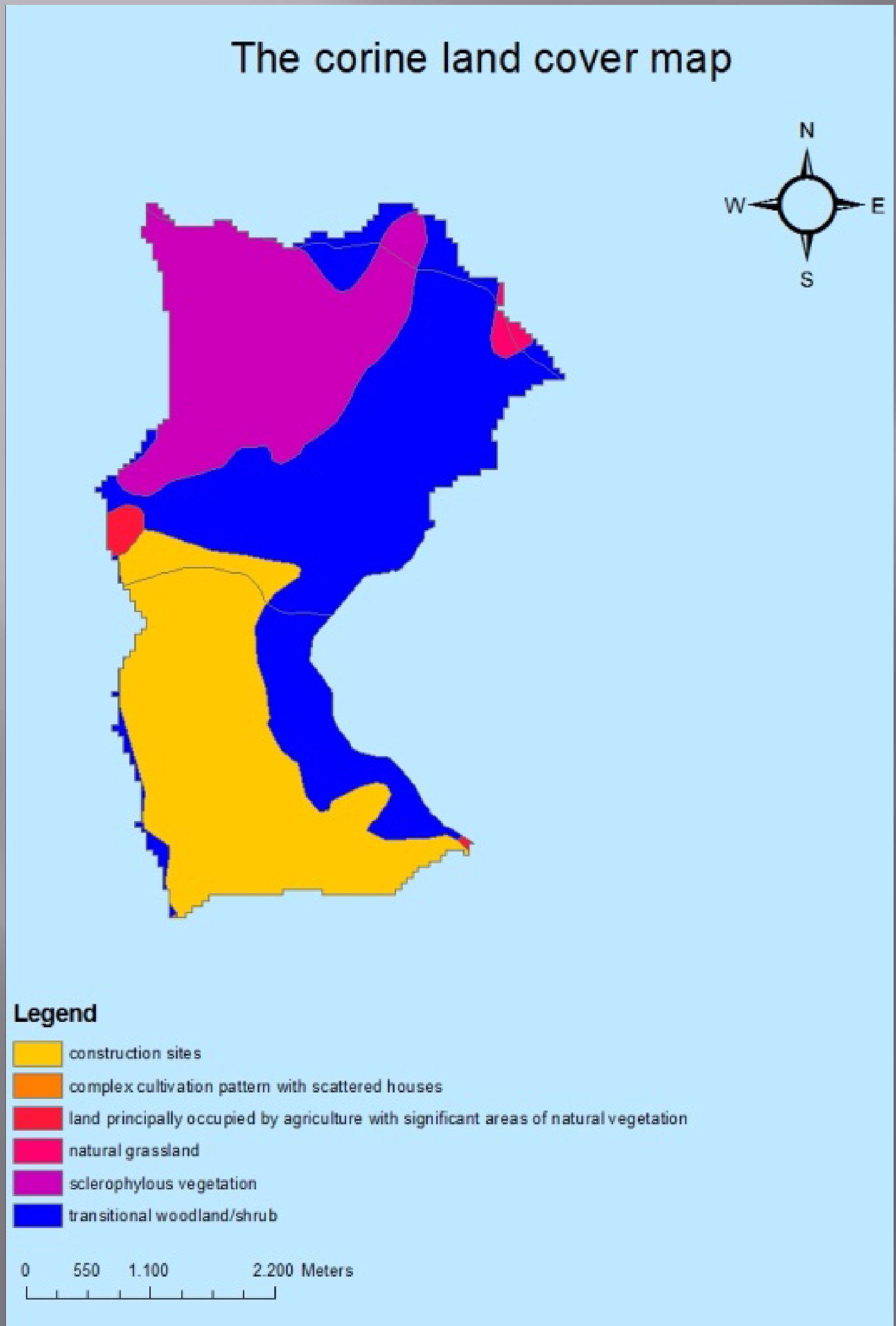
Remark: The SCS-CN & SUH is expected to be the main procedure for the estimation of flood hydrographs within the implementation of the 2007/60/EU Directive in Greece

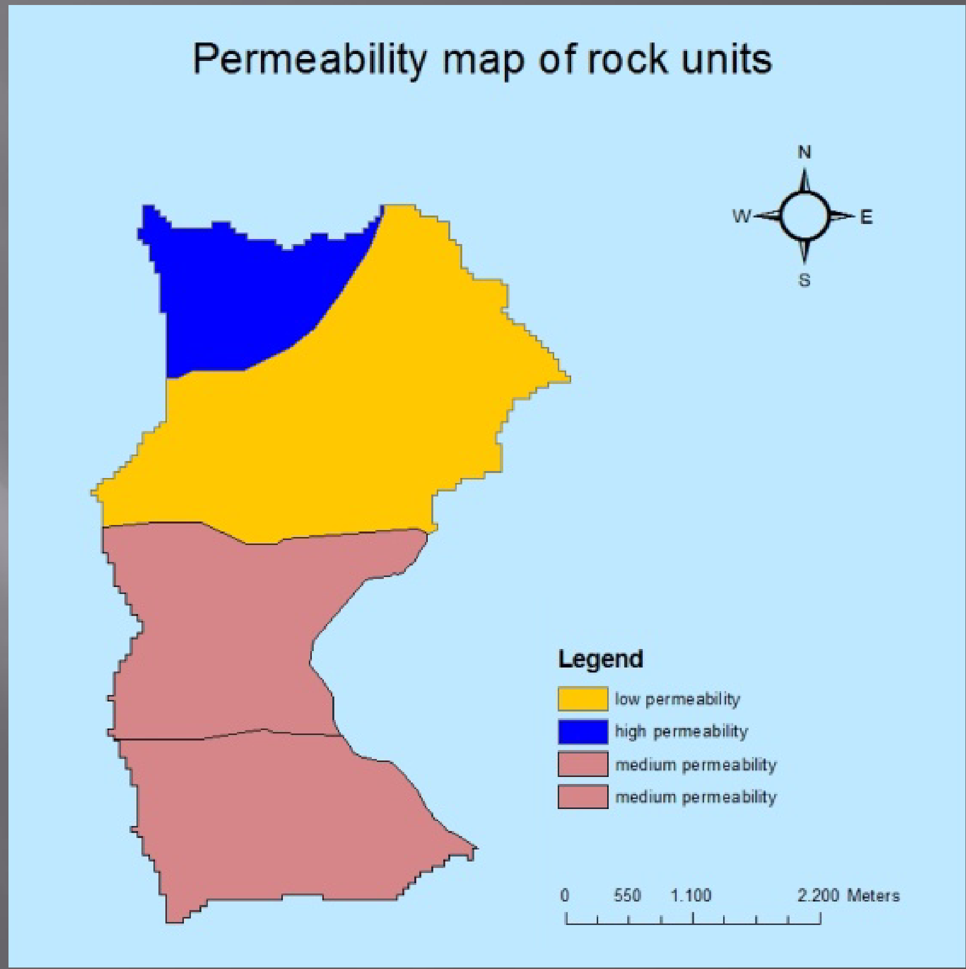
Study basin: Lykorema, Penteli



- Small mountainous basin ($15.2\ km^2$), located in the eastern side of Mt. Penteli
- Steep relief, poor vegetation, dominance of flash floods
- Experimental basin (from 2005), maintained by the Hydrological Observatory of Athens (http://hoa.ntua.gr/)
- Telemetric monitoring network, comprising three meteorological and two hydrometric stations (Lykorema, Drafi)

Geographical data

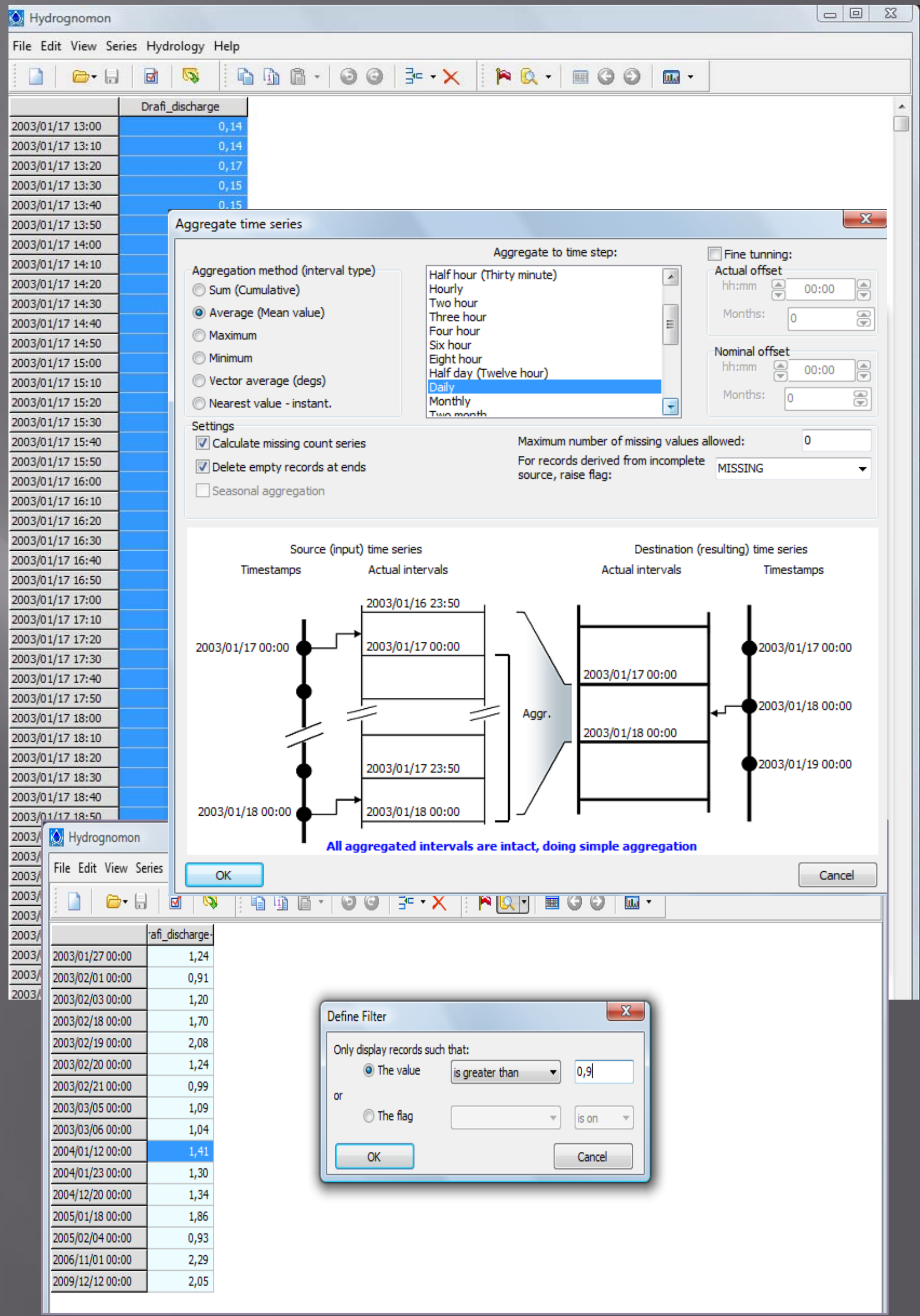




On the basis of CORINE land cover and permeability maps, we estimated the runoff curve number of the upstream (CN = 76) and the total basin (CN = 73)

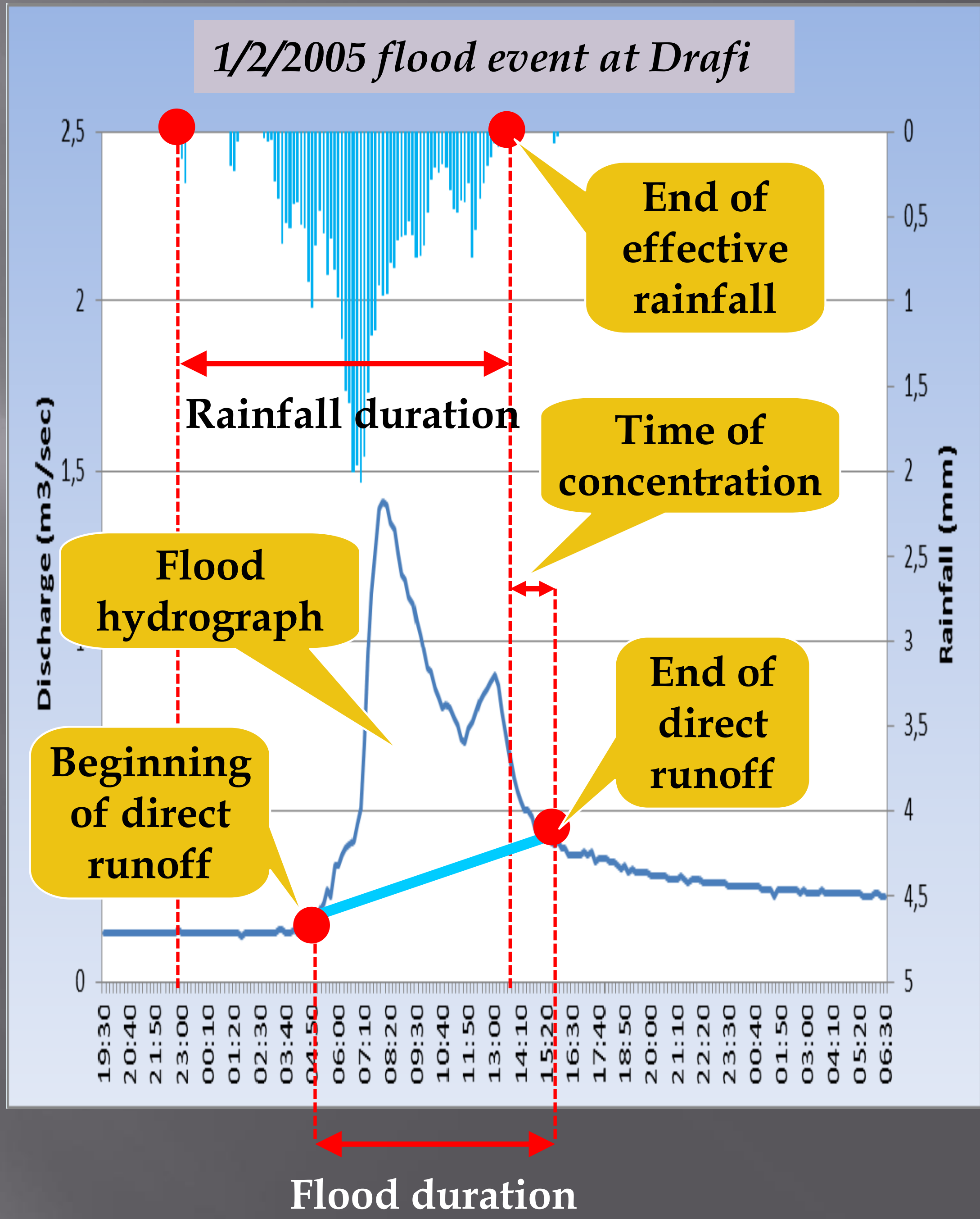
Selection of flood events & data processing

- Retrieval of 10-min discharge time series at the two flow stations (2005-11)
- Aggregation to mean daily discharge, using the Hydrognomon software
- Selection of most important flood events, based on daily discharge and other criteria
- Assignment of finely-resolved (10 min) rainfall and discharge time series to the corresponding events (20 at Lykorema, 15 at Drafi)



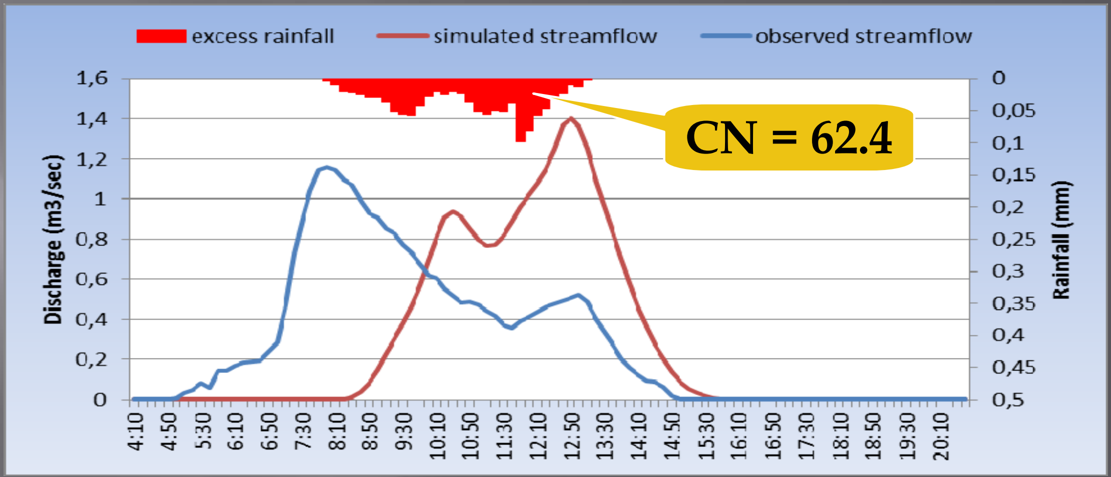
Analysis of observed flood events

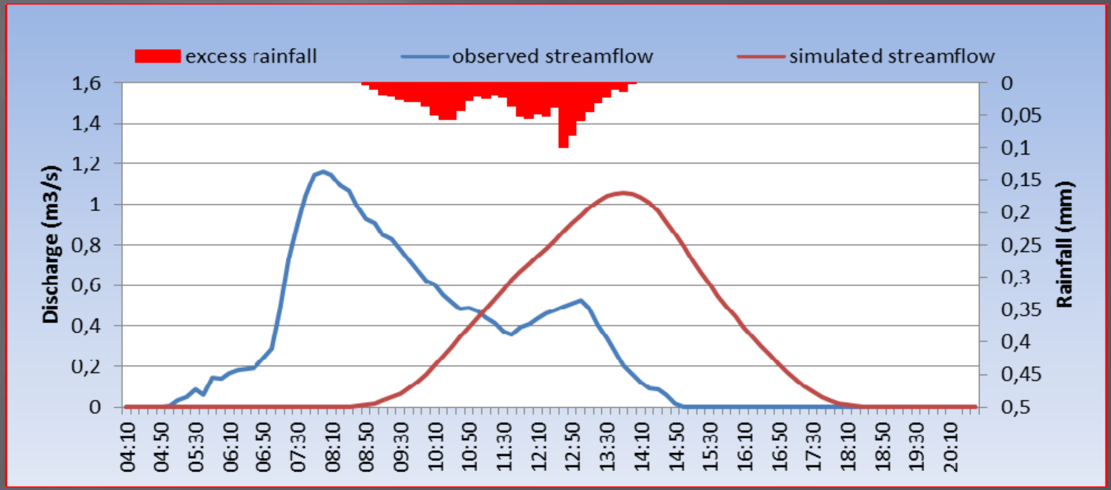
- Extraction of effective rainfall and direct runoff from the observed events
- Key assumptions:
  - Direct runoff begins when the hydrograph gradient increases sharply
  - The end of effective rainfall coincidences the end of total rainfall
  - The distance between the end of effective rainfall and the end of direct runoff equals the time of concentration, estimated via the Giandotti formula



Testing of the SCS-CN & SUH approach

- Estimation of effective rainfall through the SCS-CN model and transformation to flood hydrograph, using the SUH of Snyder and of the British Hydrological Institute (BHI)
- Key assumptions:
  - For all events, the initial abstraction ratio was set equal to $a = 0.20$
  - For each event, the maximum soil moisture retention was analytically computed, as function of the flood volume
  - The corresponding CN was estimated assuming initial soil moisture conditions of type II



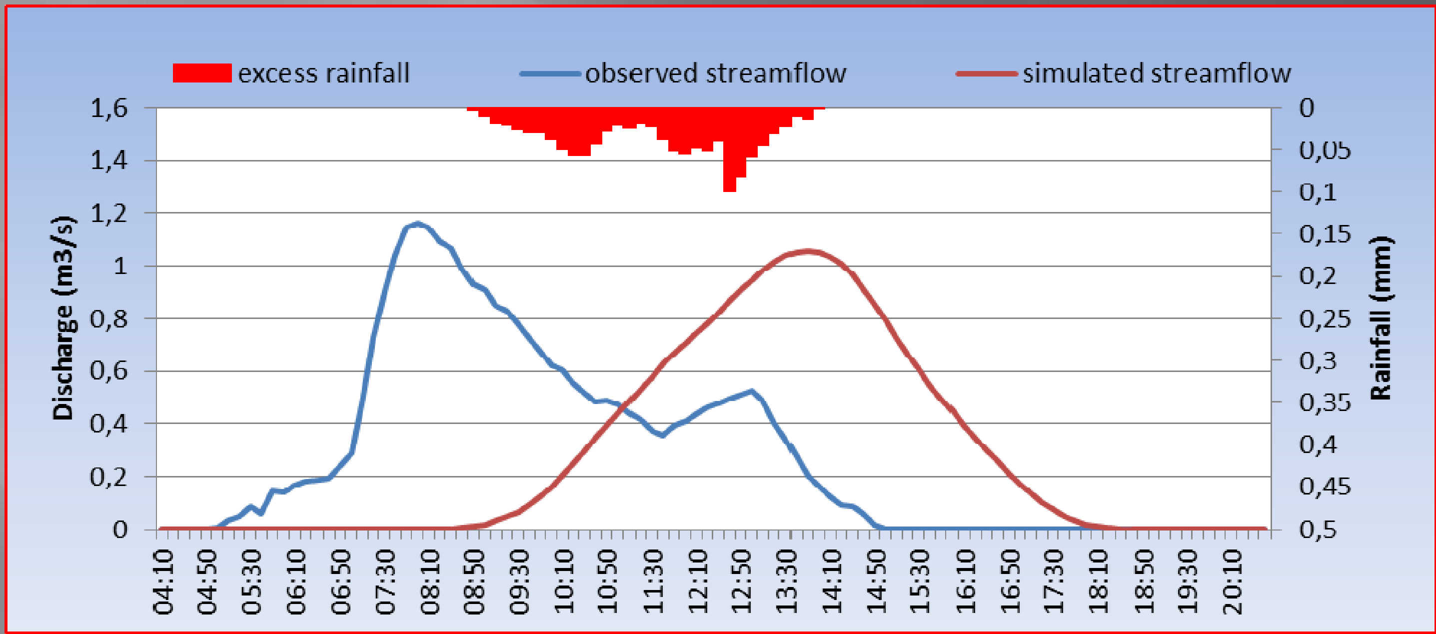


Comparison of hydrographs derived by employing the SUH of the Snyder (up) and the BHI (down)

Explanation of inconsistencies

The effective rainfall appears much later than the observed direct runoff, indicating that initial losses are seriously overestimated

The SCS-CN model parameters (*a* and CN) are not properly determined



The rising branch of the observed hydrograph is much sharper than the simulated one, while the falling branch is smoother

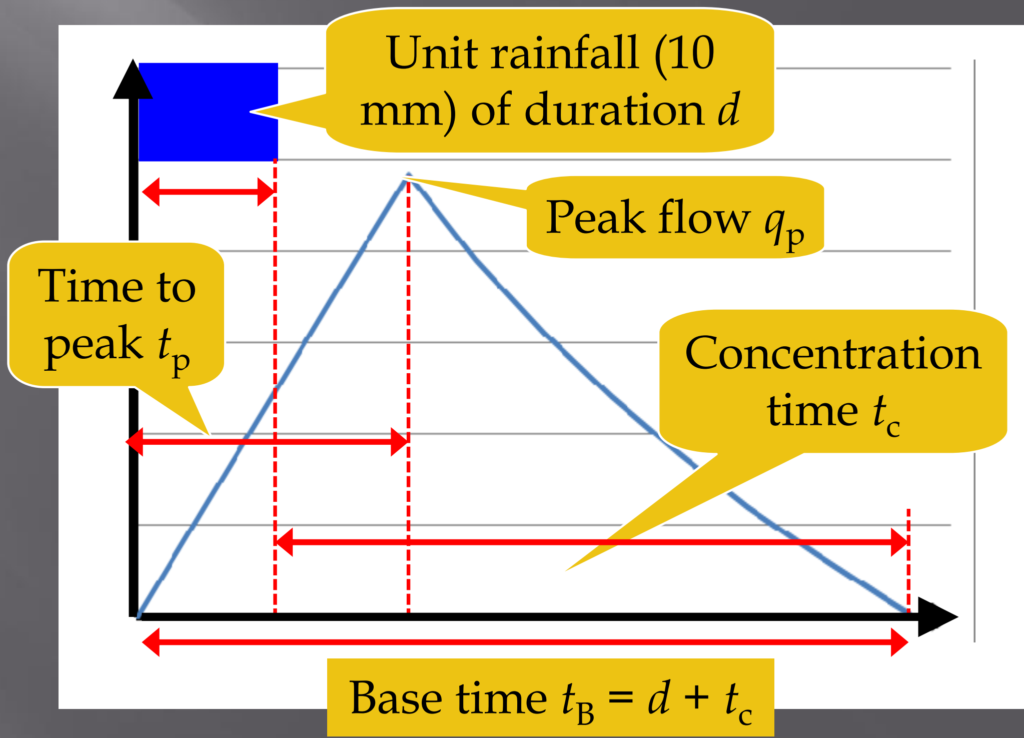
The shape of the unit hydrograph is not consistent with the basin geomorphology

Development of a parametric SUH

- The concept of a parametric SUH supposes an analytical expression for its shape, using few parameters
- Following the usual definition of time of concentration t_c, the base time is $t_B = d + t_c$, where d is the rainfall duration
- The time to peak is given by $t_p = d/2 + b\ t_c$, where $b < 1$ is the single parameter of the SUH (provided that t_c is estimated through one of the known empirical formulas)
- The SUH comprises a linear rising branch and a falling one, given by a logarithmic function of the form:

  $$q(t) = q_p - k \ln(1 + t - t_p)$$

  where k and q_p (peak flow) are analytically computed



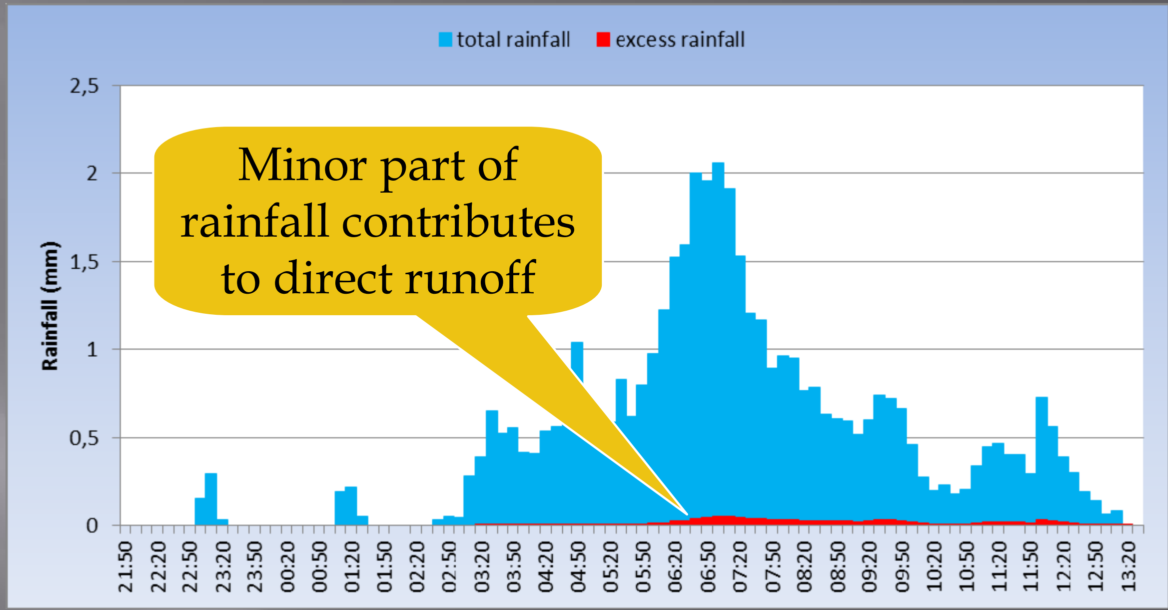
Model fitting through calibration

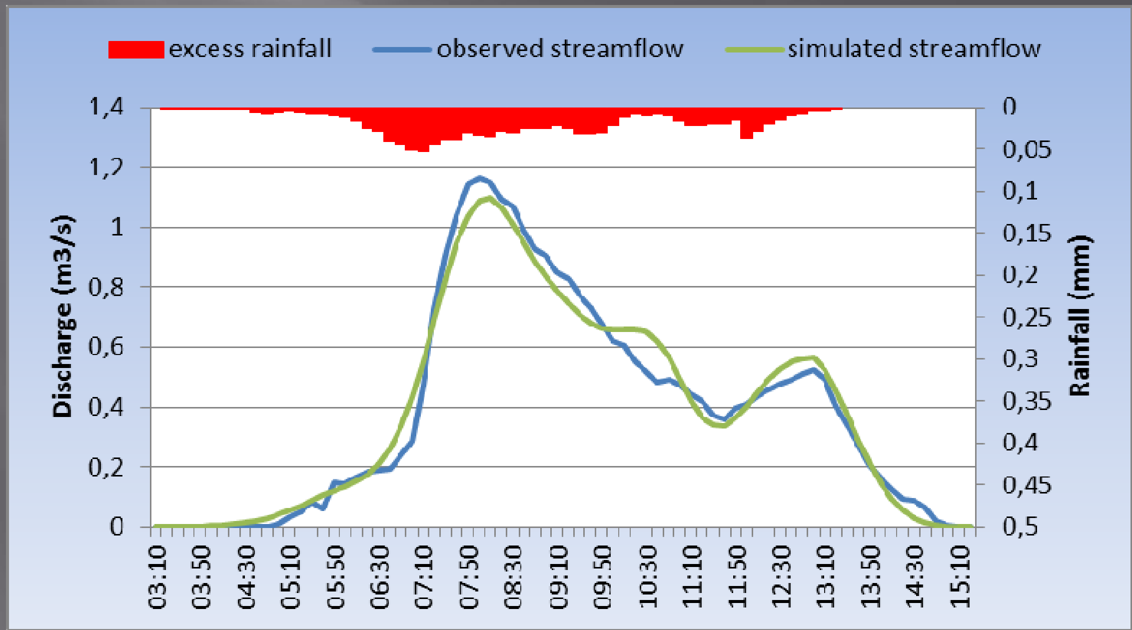
- For each event, three parameters of the SCS-CN & SUH scheme were assumed unknown, thus requiring calibration:
  - the initial abstraction ratio *a* (dimensionless);
  - the curve number CN ($0 < CN < 100$);
  - the time parameter *b* of the SUH (dimensionless).
- A weighted objective function was formulated comprising the following components:
  - the root mean square error between the observed and simulated hydrographs (evaluates the overall fitting of the model);
  - a penalty term for the representation of the observed peak flow;
  - a penalty term for the maintenance of the observed flood volume (physical constraint).
- Preliminary investigations were employed in order to assign suitable values to the weighting coefficients

Application to the flood event of 1/2/2005

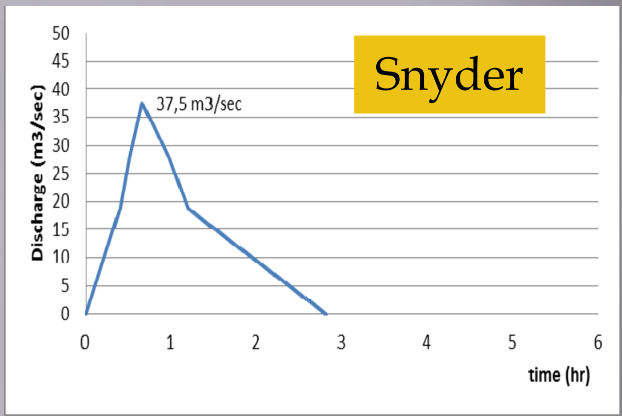
- Flood characteristics
  - Total rainfall 44.3 mm
  - Equivalent depth of direct runoff (effective rainfall) 1.13 mm
  - Runoff coefficient 2.6%
  - Observed peak discharge 1.16 m^3/s
- Optimized parameters
  - $a = 0$, CN = 14
  - $b = 0.53$

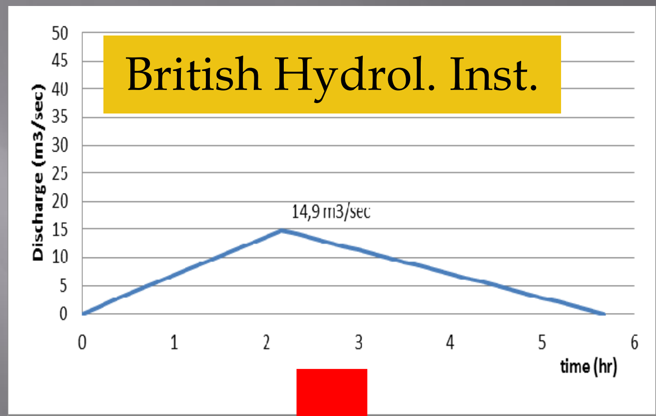
The **parsimonious** SCS-CN & SUH approach is suitable for representing hydrographs of any complexity – but what about its parameters?

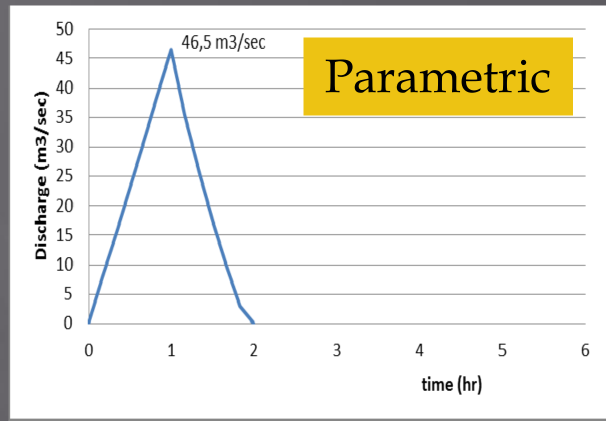


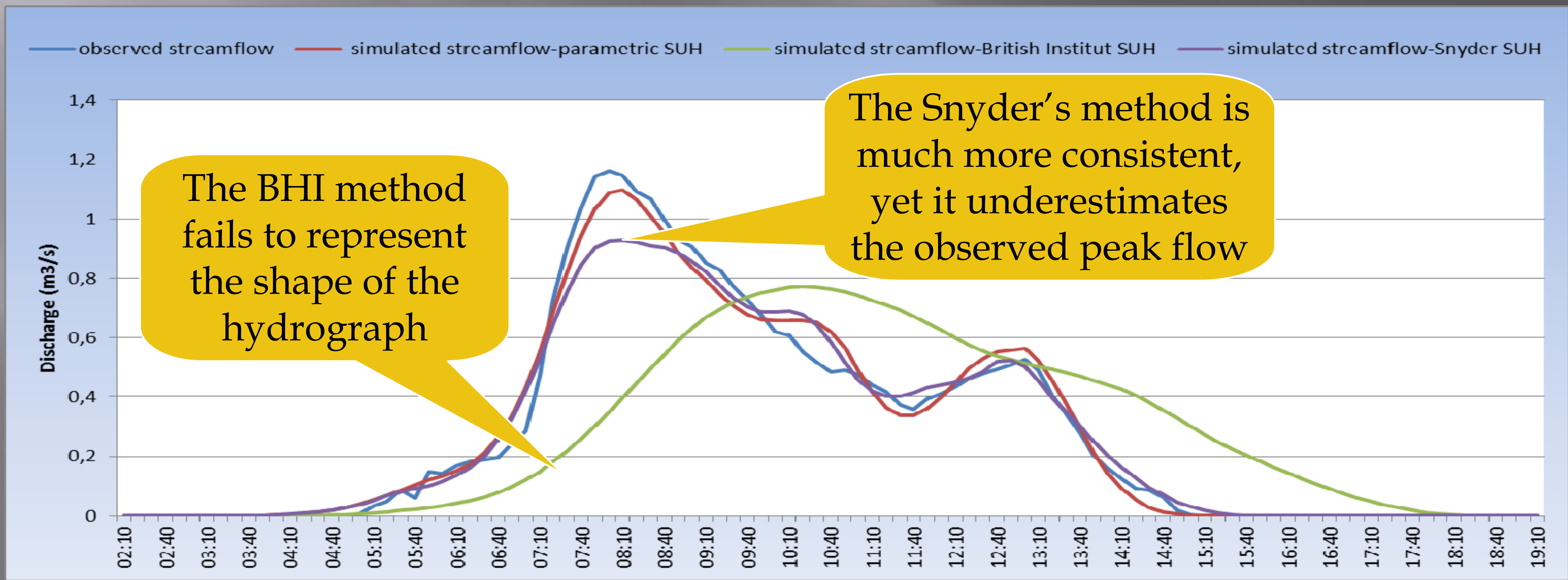


Comparison of SUHs (employing the optimized *a* and CN values)

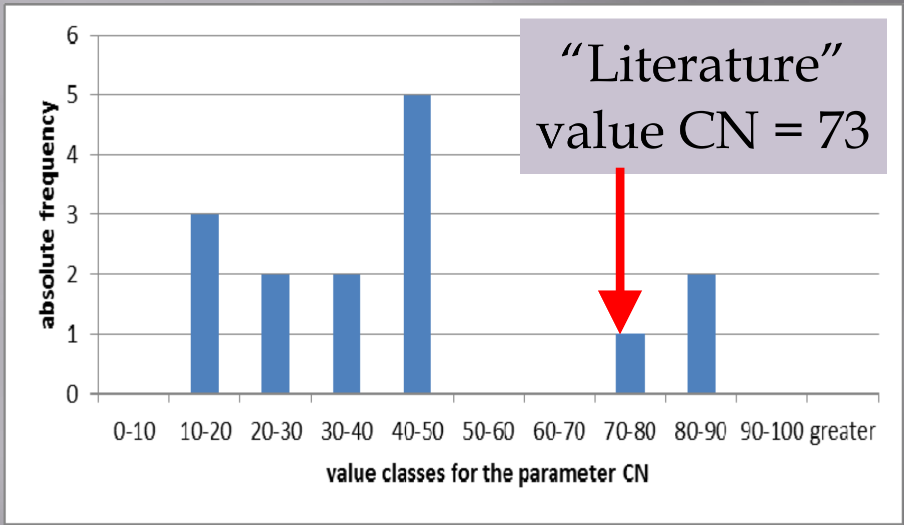


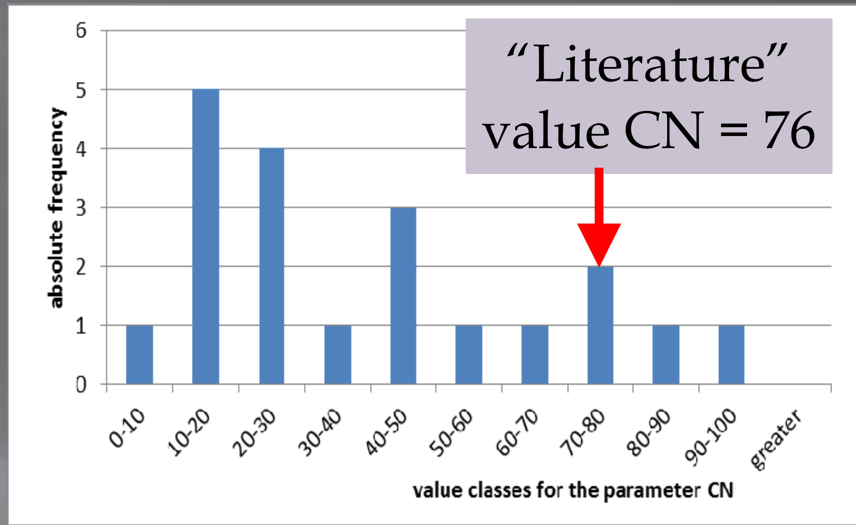


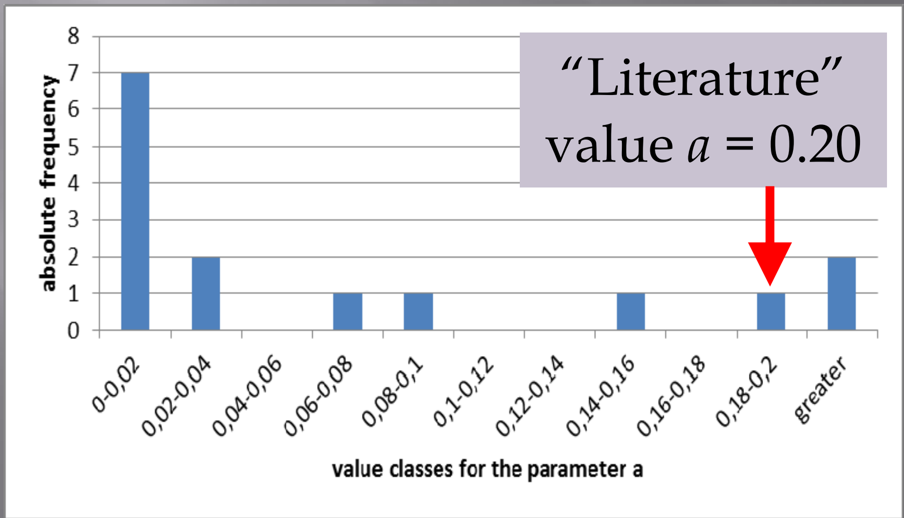


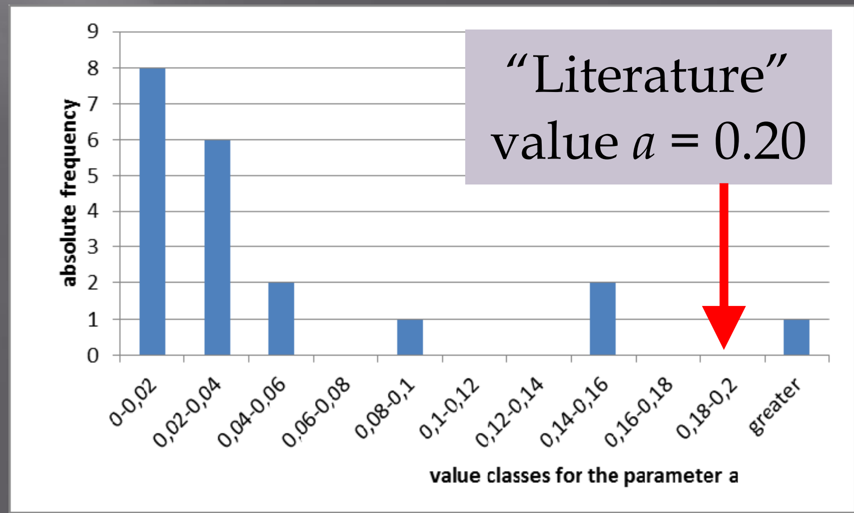


Classification of optimized parameter values of the SCS-CN method





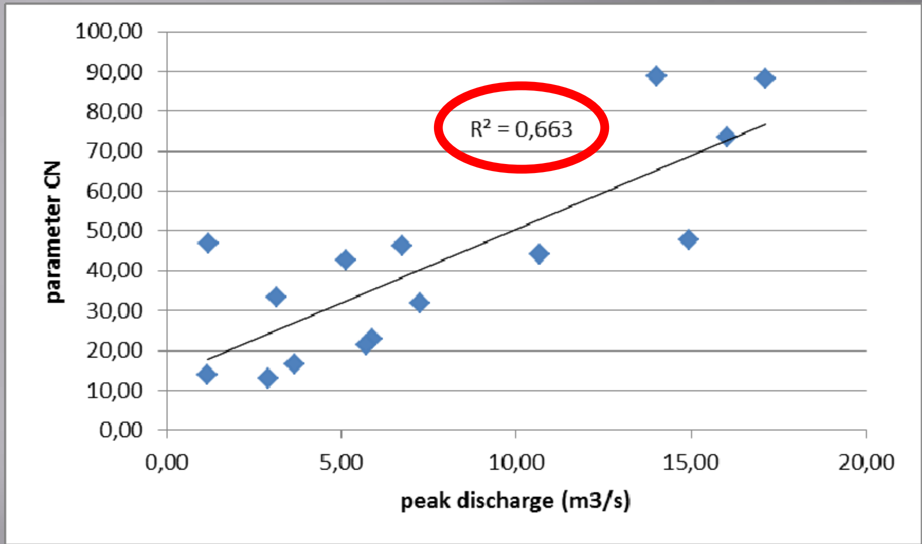


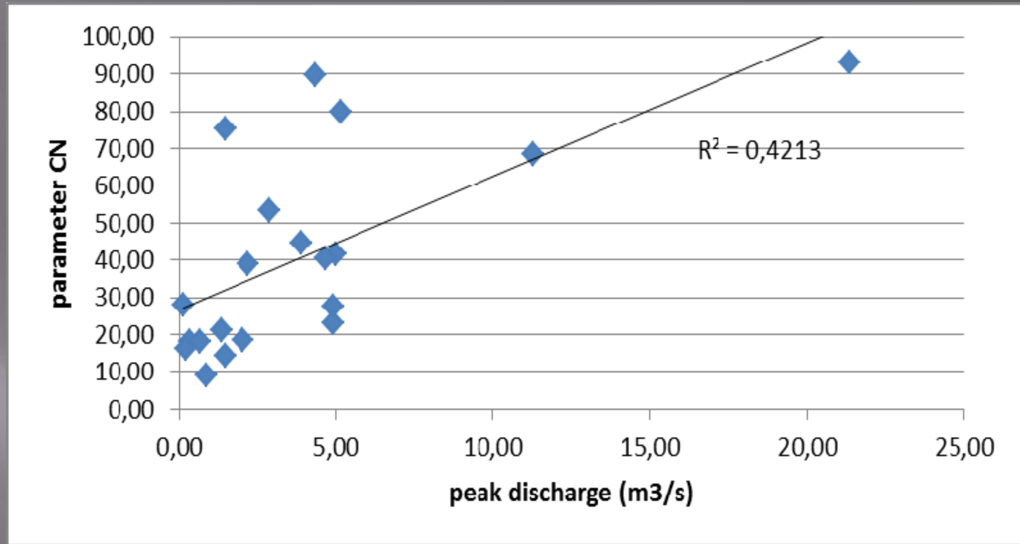


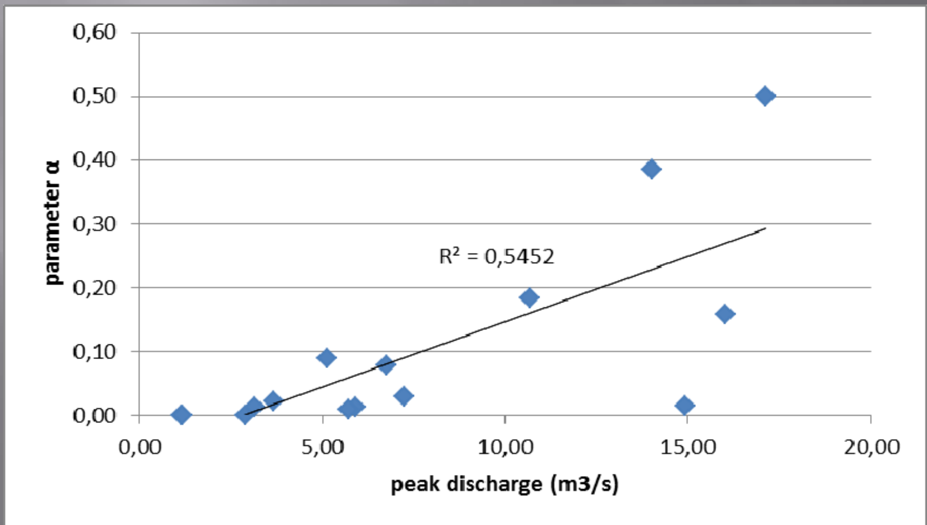
Drafi station (whole basin)

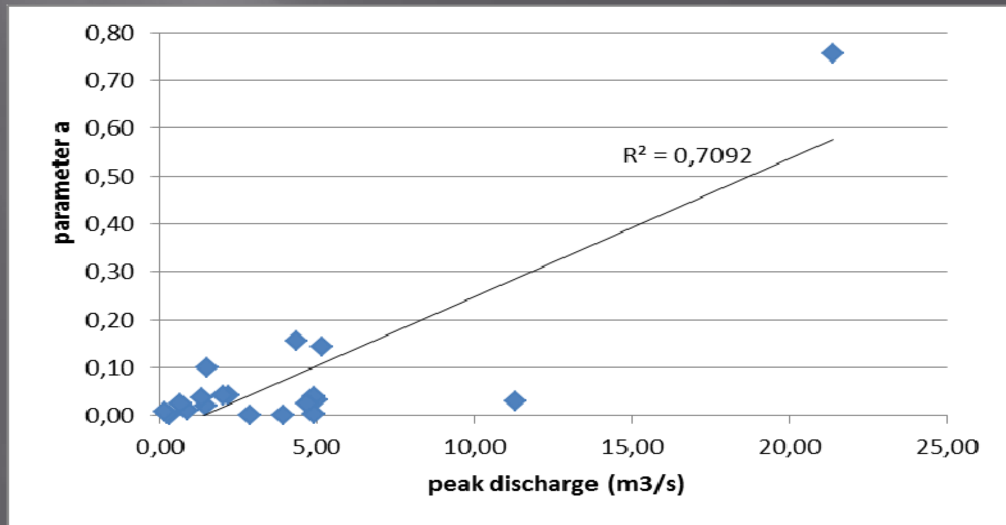
Lykorema station (upstream basin)

Correlations of optimized SCS-CN parameters with peak discharge





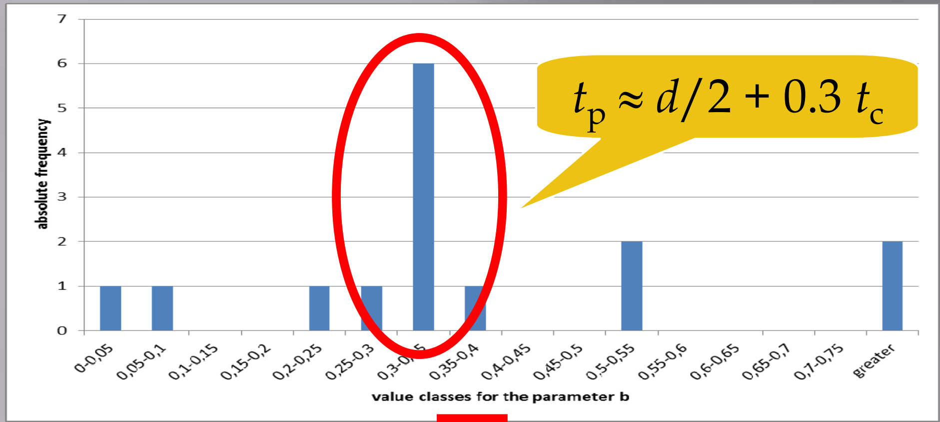


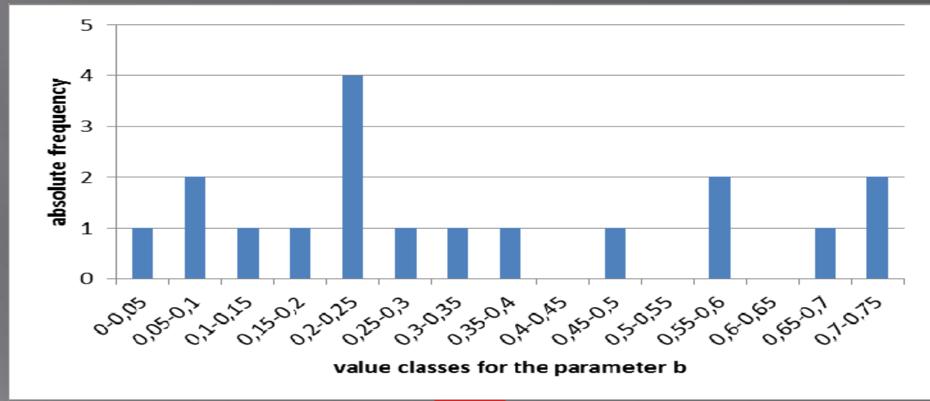


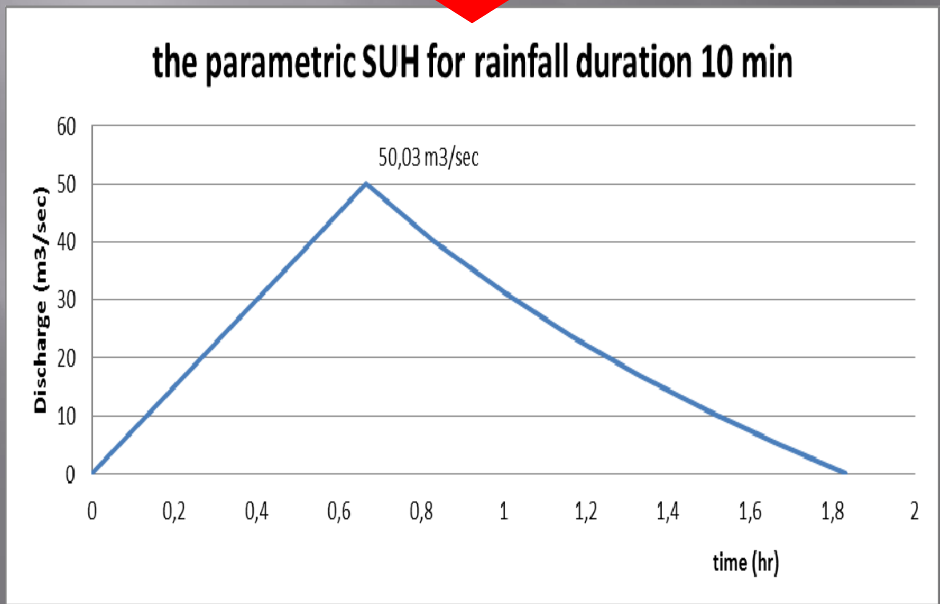
Drafi station (whole basin)

Lykorema station (upstream basin)

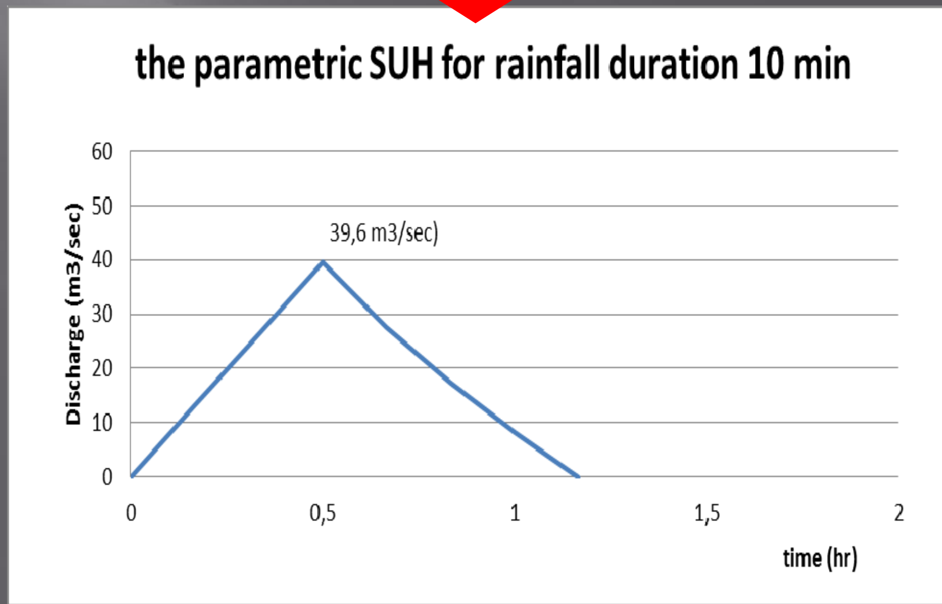
Classification of optimized parameter *b* and formulation of "average" SUHs





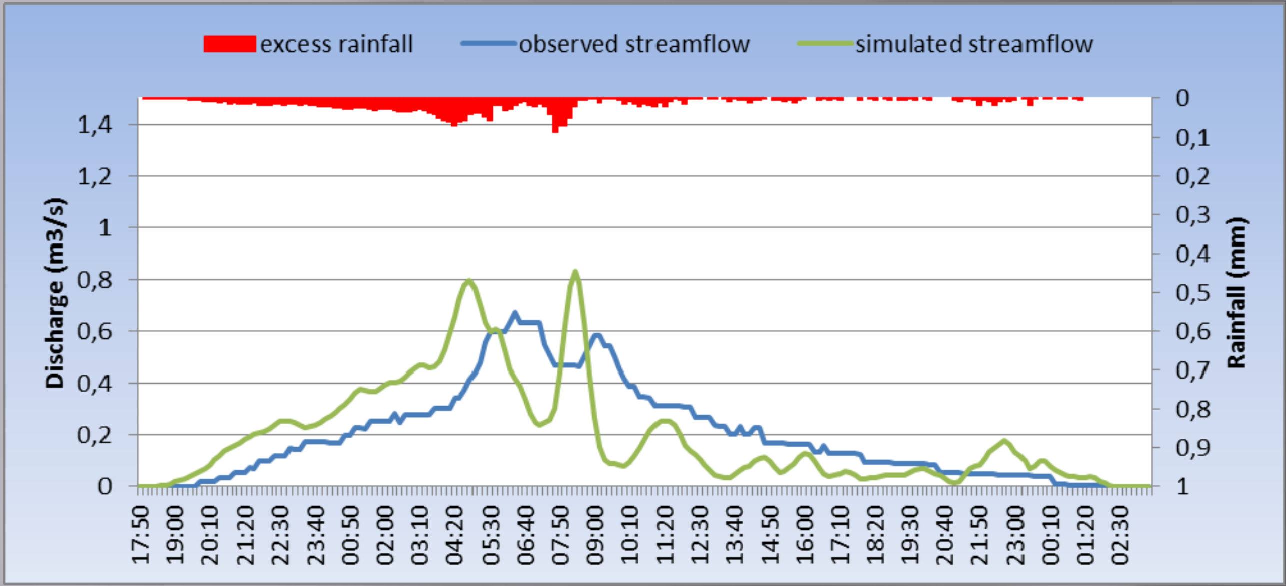


Drafi station (whole basin)

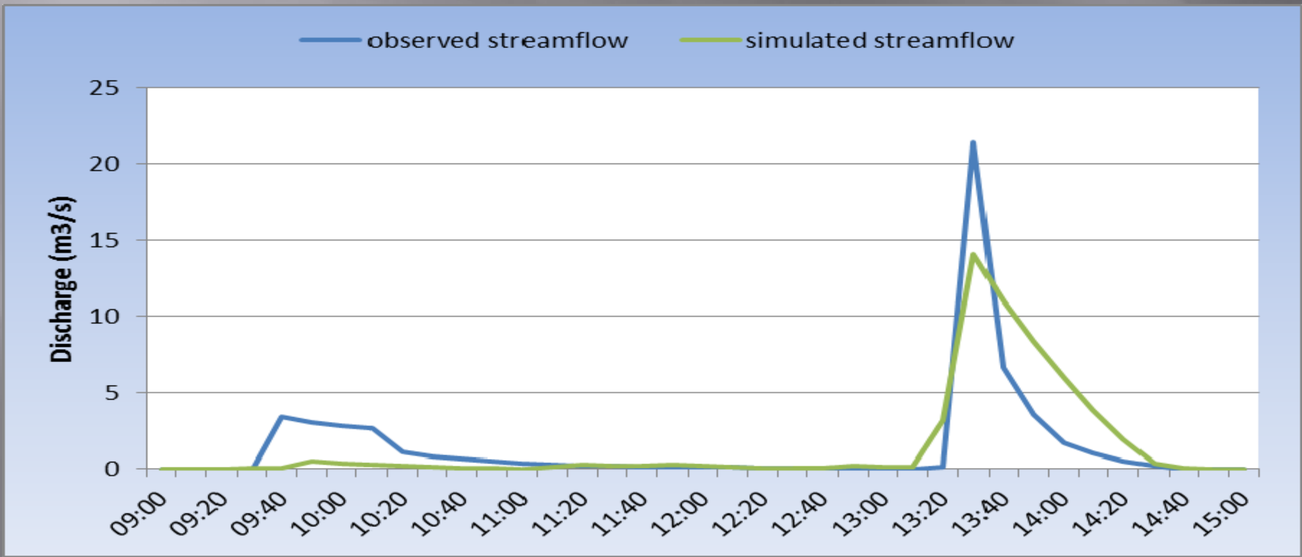


Lykorema station (upstream basin)

Characteristic cases of model failure



Case 1: Smooth hydrographs, low flows, long duration



Case 2: Very sharp hydrographs of short duration, generating high peak values

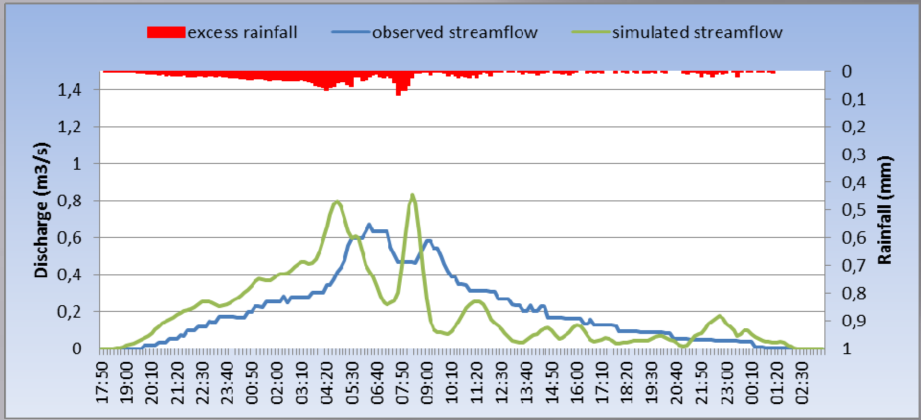
Different cases, common origin: time of concentration

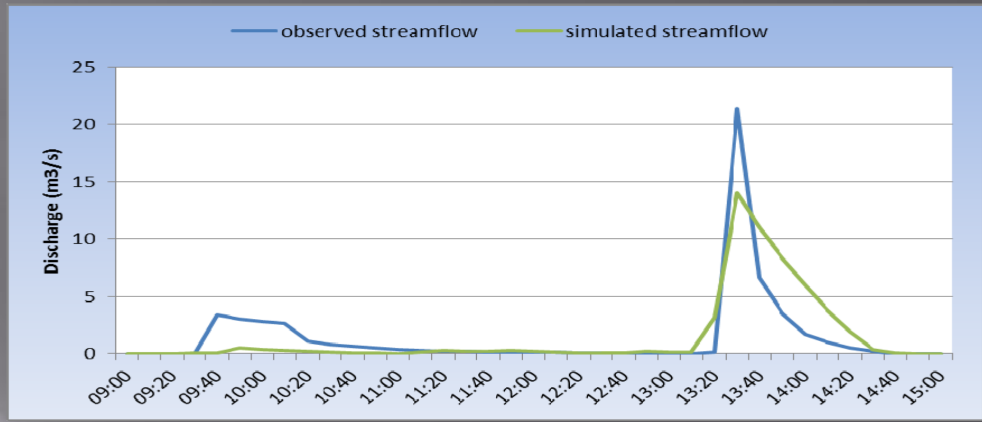
Re-formulation and re-calibration of parametric SUHs

- Apart from parameter *b*, related with the time of peak, an additional parameter is introduced, related with the base time, now expressed as $t_b = d + c\, t_c$, with $c > 0$.
- For convenience, t_c represents the standard time of concentration by Giandotti, while $t_c^* = c\, t_c$ represents an adjusted value, to be estimated through calibration.
- For each flood event, parameters *b* and *c* were calibrated, while for the SCS-CN method, the already optimized parameter values were used.

The assumption of a varying time of concentration is absolutely consistent with the process physics: as rainfall increases, discharge increases, flow velocity increases and thus the “travel time” of runoff across the basin decreases.

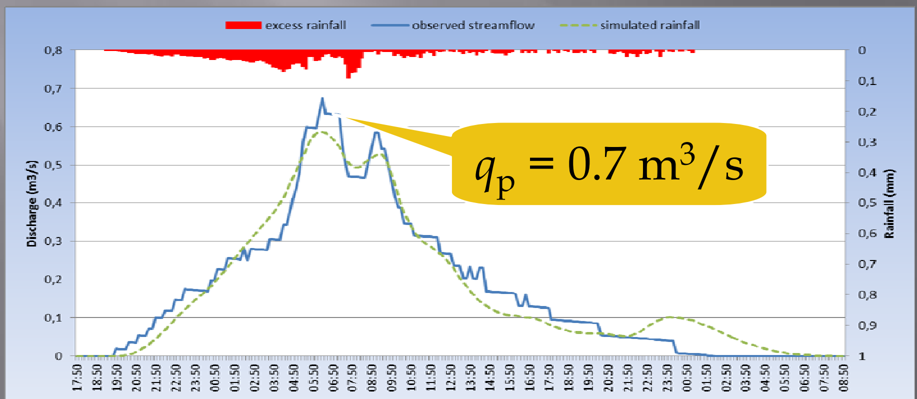
Improvement of flood predictions assuming variable time of concentration

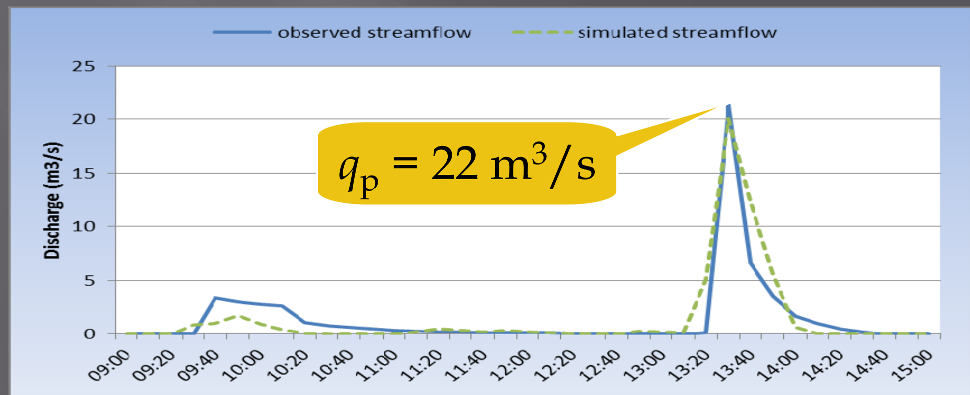




$b = 0.33$, $t_c = 70$ min

$b = 0.07$, $t_c = 70$ min

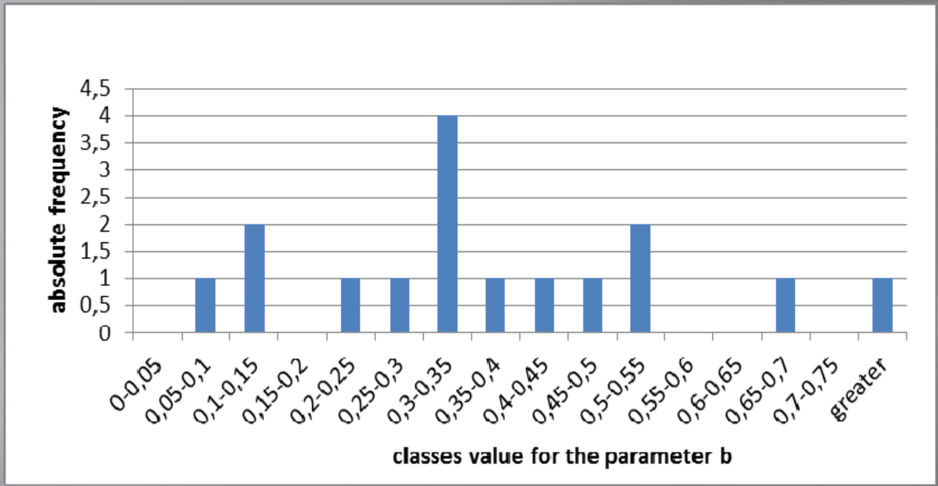


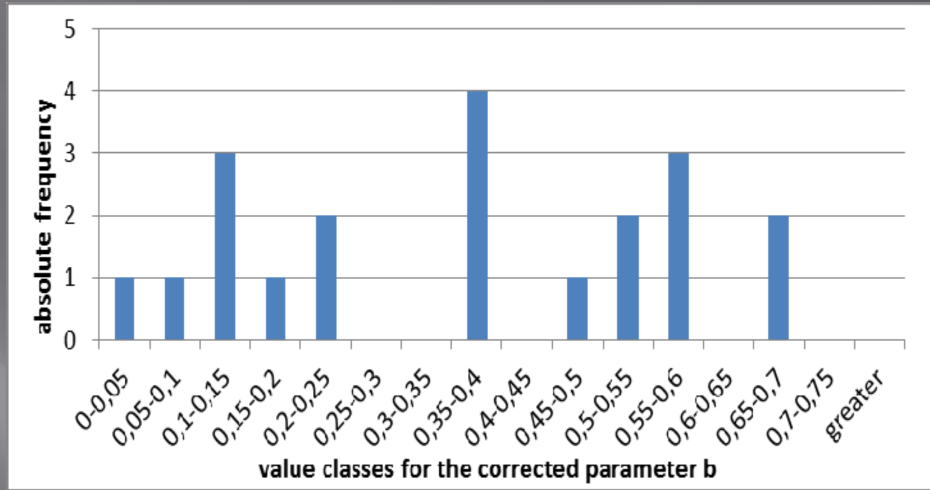


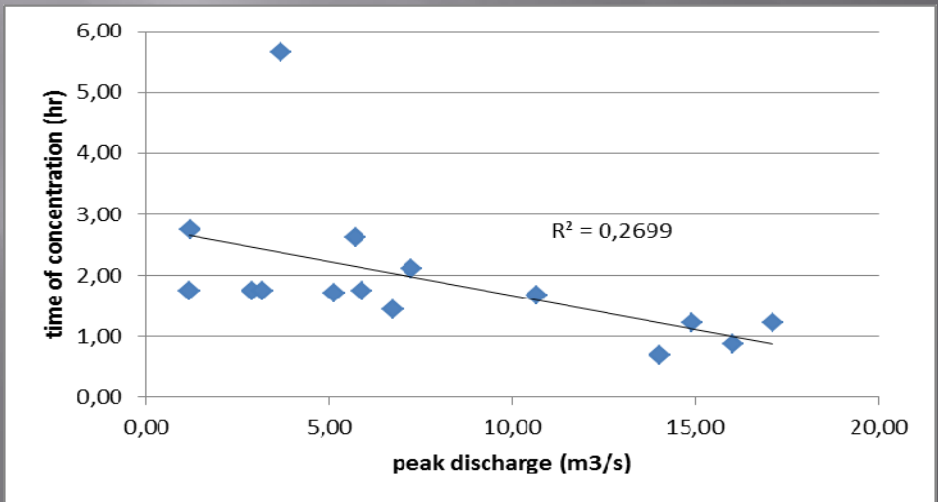
$b = 0.21$, $t_c^* = 450$ min

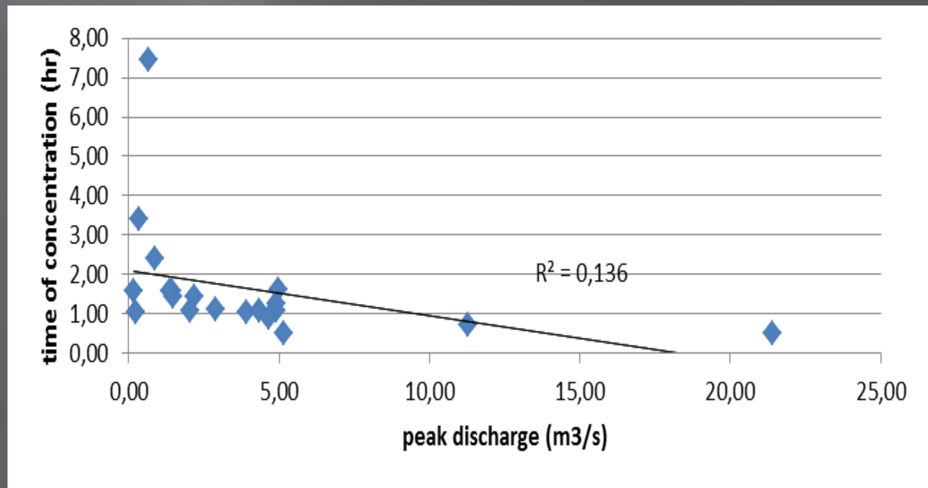
$b = 0.08$, $t_c^* = 40$ min

Classification of re-optimized parameter *b* and correlation of t_c^* with peak discharge









Drafi station (whole basin)

Lykorema station (upstream basin)

Answers to preliminary questions (based of the specific sample of floods events)

- How realistic are the assumptions of the flood modeling procedure, based on the SCS-CN & SUH approach?
  - The conceptual SCS-CN model, with calibrated parameters per event, represents with satisfactory accuracy the processes that contribute to the generation of direct runoff.
  - Between the two typical (non-parametric) SUHs , the Snyder's model exhibits better performance than the BHI.
  - The parametric SHU is much better fitted to the geomorphology of the specific basin (sharper rising branch, higher peak flow).
- How suitable are the existing empirical formulas for the estimation of the various model parameters?
  - The literature values for the two parameters of the SCN-CN model are not realistic – in general, they are significantly overestimated.
  - For most (but not all) events, the Giandotti formula for the calculation of the time of concentration worked well.

Answers to preliminary questions (cont.)

- Which of them are, in fact, constants and which should be regarded as variables?
  - The CN is definitely not a constant but a variable, absolutely depending on the antecedent soil moisture conditions.
  - The initial abstraction ratio exhibits limited variability, thus it can be assumed as constant, related to the basin's retention capacity.
  - The time of concentration is decreasing function of discharge.
- Which aspects of the whole methodology should be revised, in order to be consistent with the peculiarities of the Greek basins?
  - Formulation of more representative SUHs (parametric?)
  - Development of easy to implement formulas, linking the varying "parameters" of the SCS-CN & SUH approach, such as CN and t_c, with a characteristic design magnitude (return period?)
  - Proper evaluation of flood risk by accounting for the variability of soil moisture (continuous simulation?)

This presentation is available on-line at:

http://itia.ntua.gr/en/docinfo/1290/

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