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

University of Thessaly, Volos, 24-26 October 2012

Flood design recipes vs. reality: Can predictions for ungauged basins be trusted? – A perspective from Greece

Andreas Efstratiadis[1], Antonis Koussis[2], Demetris Koutsoyiannis[1], Nikos Mamassis[1], and Spyros Lykoudis[2]

(1) Department of Water Resources & Environmental Engineering, National Technical University of Athens

(2) Institute of Environmental Research & Sustainable Development, National Observatory of Athens

Motivation: Floods, flood engineering and flood science

- Disasters caused by large floods increase worldwide
  - as result of the changing environment (urbanization, deforestation)
  - despite the development of better infrastructures, better forecasting systems and better management plans.
- Engineering practice vs. advances in hydrological sciences
  - Many flood protection structures are still designed using simplistic rules-of-thumb and semi-empirical approaches;
  - Most of engineering "recipes" were developed many decades ago but they have never been validated and adapted to local conditions;
  - Although typical engineering knowledge is far behind scientific advances, too little attention is spent to mitigate this gap;
  - Too little research funding is provided for practical issues in flood hydrology – most of proposals are rejected as "trivial".

See relevant lecture by Koutsoyiannis (2012) titled "*Reconciling hydrology with engineering*"

Further motivation: The Greek case

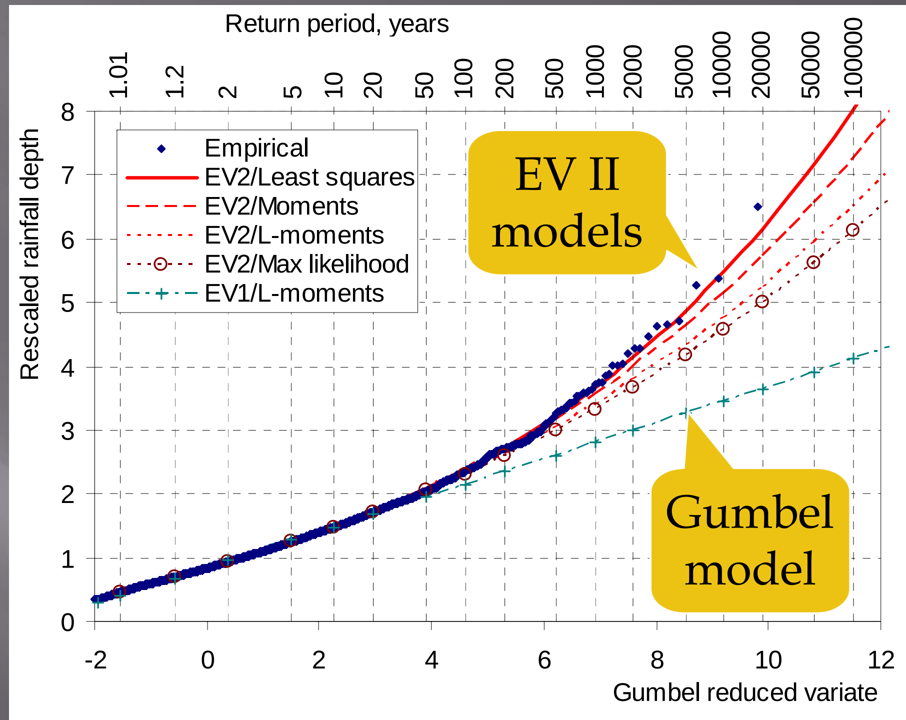
- Greek basins exhibit significant peculiarities with regard to their hydroclimatic regime and geomorphology
  - Semi-arid climate (Eastern Greece and Aegean islands) yet characterized by intense storms that generate flash floods;
  - Highly fragmented geometry, formulation of numerous small and medium scale basins (typical areas 50 to 250 km^2), steep terrain;
  - Domination of highly-permeable formations (~40% carbonate), surface and groundwater interactions, ephemeral flows.
- Greece lacks reliable flood data
  - With few exceptions, Greek basins are ungauged;
  - Even in gauged rivers, finely-resolved hydrometric data is of questionable accuracy (rating curves?) and hardly accessible;
- Greece lacks guidelines and specifications for flood studies; it also lacks know-how to respond to the advanced requirements of the 2007/60/EU Directive.

Flood design recipes vs. reality: The rational method ($q = c\,i\,A$)

- The rational equation, proposed in 1850 by the Irish engineer T. J. Mulvany, is still the typical design tool in small ungauged basins and for urban drainage studies.
- Its implementation is based on the following "recipe":
  - Assign a statistical model to the rainfall maxima and implement idf analysis (preferably through the Gumbel model , which has an attractive analytical expression, easily handled in a spreadsheet);
  - Compute the time of concentration of the basin from a literature formula (doesn't mater which) and set it equal to rainfall duration;
  - Compute the corresponding critical rainfall intensity and reduce this value, using an areal reduction formula (never mind if this was developed for storms that are generated by typhoons);
  - Select a runoff coefficient from a table with typical values (hoping to find a soil class that resembles your basin characteristics);

The rational method recipe vs. reality: (a) Selecting "rational" statistical models

- For return periods > 50 years, the widely-used Gumbel (EV1) distribution results to significantly lower values of the design rainfall than other extreme models, e.g. EV II.
- Statistical investigations using large samples worldwide prove that heavily-tailed distributions are in better agreement with the observed rainfall extremes (Papalexiou *et al.*, 2012).



EV2 (more known as GEV) and EV1 (Gumbel) distributions fitted by several methods and comparison with the empirical distribution for a record of all 169 annual maximum rescaled daily rainfall series (18 065 station years; chart reproduced by Koutsoyiannis, 2004)

The rational method recipe vs. reality: (b) The time of concentration paradox

- The time of concentration is key issue in flood modeling.
- The concept is unambiguous, since there exist different definitions for t_c (at least eight, according to McCuen, 2009).
- There are numerous empirical formulas and computational procedures for t_c, without reference to a specific definition.
- Theoretical evidence and experiments indicate that t_c is not a constant, but decreases with flow (Grimaldi *et al.*, 2012).
- Q depends on t_c and vice versa: a puzzle for engineering hydrology!

Time of concentration: a paradox in modern hydrology

S. Grimaldi[1,2,3], A. Petroselli[4], F. Tauro[3,5] and M. Porfiri[3]

[1]*Dipartimento per l'Innovazione nei sistemi Biologici, Agroalimentari e Forestali (DIBAF Department), University of Tuscia, Via San Camillo De Lellis, I-01100 Viterbo, Italy*
salvatore.grimaldi@unitus.it

[2]*Honors Center of Italian U*

[3]*Department of Mechanica*
NY 11201, USA

[4]*Dipartimento di scienze e*
Via San Camillo De Lellis,

[5]*Dipartimento di Ingegneri*

Received 13 September 2

Editor D. Koutsoyiannis

Citation Grimaldi, S., Petroselli, A., Tauro, F. and Porfiri, M., 2012. Time of concentration: a paradox in modern hydrology. *Hydrological Sciences Journal*, 57 (2), 217–228.

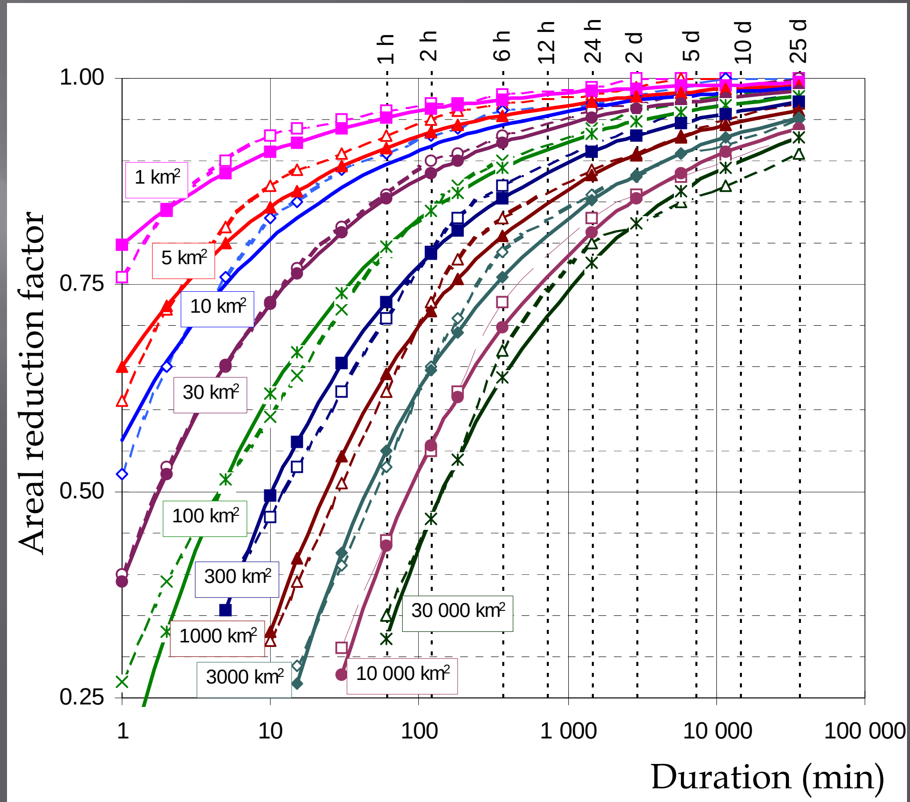
Abstract The time of concentration is a primary parameter for a variety of modern hydrological models adopted in professional and scientific communities. Nevertheless, a universally accepted working definition of this parameter is currently lacking and several definitions can be found in the technical literature along with related estimation procedures. This study brings to light the inherent variability of these definitions through the empirical analysis of four small basins. These case studies demonstrate that available approaches for the estimation of the time of concentration may yield numerical predictions that differ from each other by up to 500%.

Key words time of concentration; travel time; lag time; ungauged basins

Recent article by Grimaldi *et al.* (2012), providing new insights in the concept of t_c

The rational method recipe vs. reality: (c) "Jumping" from point to areal rainfall

- Areal reduction factors (ARF) are typically employed, which give the ratio between the areal and the corresponding point rainfall, for a specific basin area, duration and return period.
- This relationship has been also found to vary with return period, weather type and topography (e.g., Veneziano and Langousis, 2005).
- In large basins, where the spatial variability of rainfall is significant at all time scales, the ARF approach over-estimates the areal rainfall.



Nomograph derived from tabular values of ARF by NERC (1975; Koutsoyiannis, 2011)

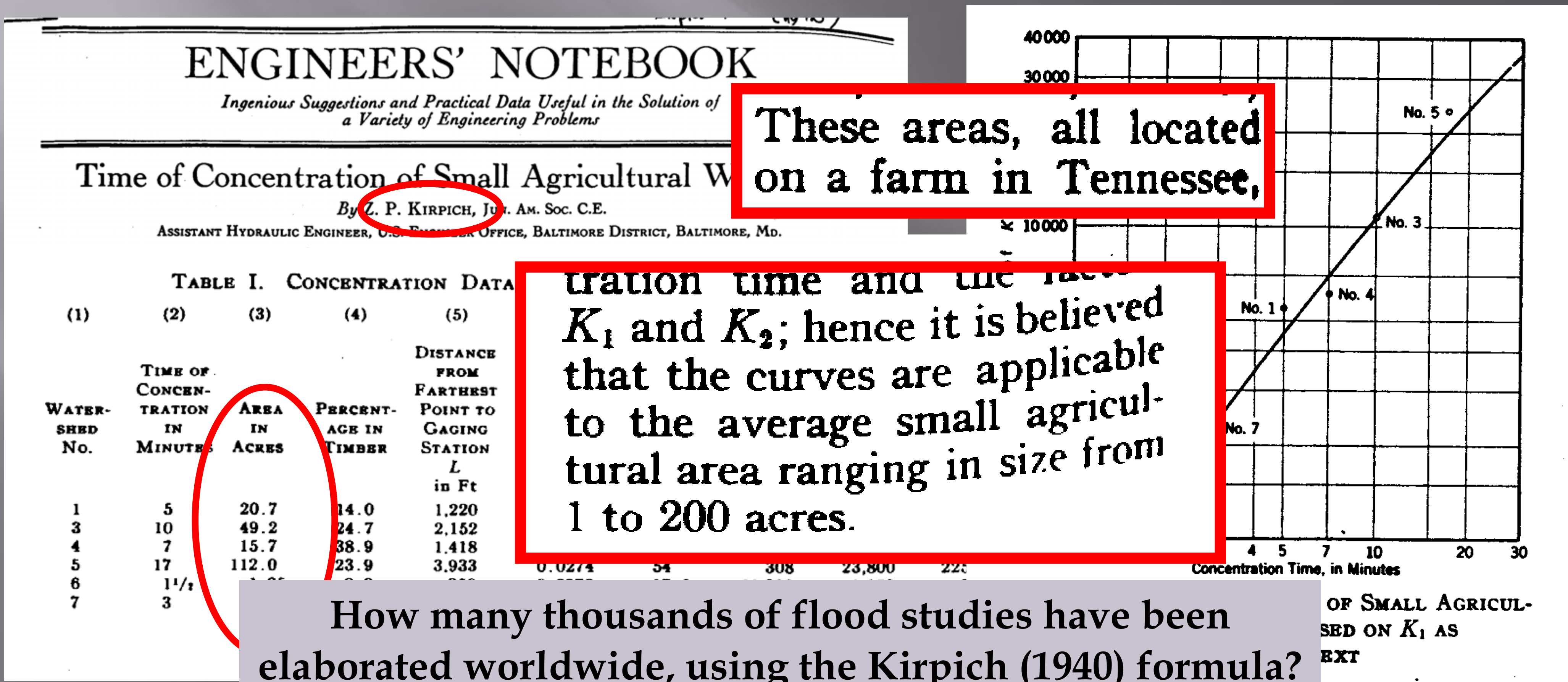
The rational method recipe vs. reality: (d) The runoff coefficient – Just a multiplier?

- The term "runoff coefficient" is widely used in hydrology to express which percentage of rainfall is transformed to runoff, and varies substantially with the aggregation scale.
- In the rational method, it is used as cut-off threshold to separate the effective from the total rainfall.
- In reality, it incorporates all uncertainties that are related with the antecedent soil moisture conditions, the temporal distribution of rainfall, etc.
- In this context, similarly to the time of concentration, it is not a characteristic parameter of the basin but a variable.

A consistent application of the "elementary" rational method is far from trivial, while a number of open research questions exist regarding all its aspects!

Regional formulas: suitable for all regions?

- Empirical regional formulas for most of design parameters were developed by employing regression analysis to field data, gathered from experimental catchments.
  - How many and how much representative are these basins?
  - Was the data adequate for obtaining reliable statistical conclusions?



How many thousands of flood studies have been elaborated worldwide, using the Kirpich (1940) formula?

Back to the beginning: data (especially, flows) (because there does not exist hydrology without hydrological data)

- Why flood flow measurements?
  - Because the current engineering recipes should be evaluated and validated against local hydroclimatic and geomorphological conditions, before being applied in practice;
  - Because it may be necessary to revise or even reconstruct from scratch, at least some of the popular recipes.
- Ok, but measurements are costly
  - The quality and reliability of hydrological studies depends on data;
  - The safety and cost of the flood-protection works depends on the quality and reliability of hydrological studies;
- Ok, but a lot of time is required to obtain long data samples
  - Measurements can (and should) be extended in both time and space;
  - As new data arrive, the "recipes" can (and should) be updated.

A perspective from Greece: The research project Deucalion*

- Full project title: Assessment of flood flows in Greece under conditions of hydroclimatic variability: Development of physically-established conceptual-probabilistic framework and computational tools
- Project info
  - Duration: March 2011 – March 2014
  - Budget: €576 000 (public funding €460 800)
  - Commissioner: General Secretariat of Research & Technology
  - Partnerships: (1) ETME Peppas & Collaborators S.A.; (2) Maheras Technical Office S.A., (3) National Technical University of Athens; (4) National Observatory of Athens

(*) In Ancient Greek mythology, Deucalion (**Δευκαλίων**) is the Biblical equivalent of Noah. Deucalion, with the aid of his father Prometheus, was saved from a major deluge caused by Zeus, by building a chest. When the waters receded after nine days, he and his wife Pyrrha, were the one surviving pair of humans (source: Wikipedia).

Project outline & work packages

WP1: Pilot basins & monitoring network

Raw meteo & flow data

Topographic & geographical data

WP2: Data processing

Hydrometeorological time series

Basin & cross-section geometry, GIS

WP3: Flood modeling tools

Statistical analysis of intense storms – IDF curves

Event-based design (semi-empirical relationships & regional methods)

Stochastic analysis of rainfall – Generation of synthetic data

Continuous approaches, coupling hydrological and hydraulic models

WP5: Assessment of methods

Back analysis of pilot flood studies at selected basins

Technical & economic comparisons

WP4: Flood forecasting

Short-term weather prediction (rainfall ensembles)

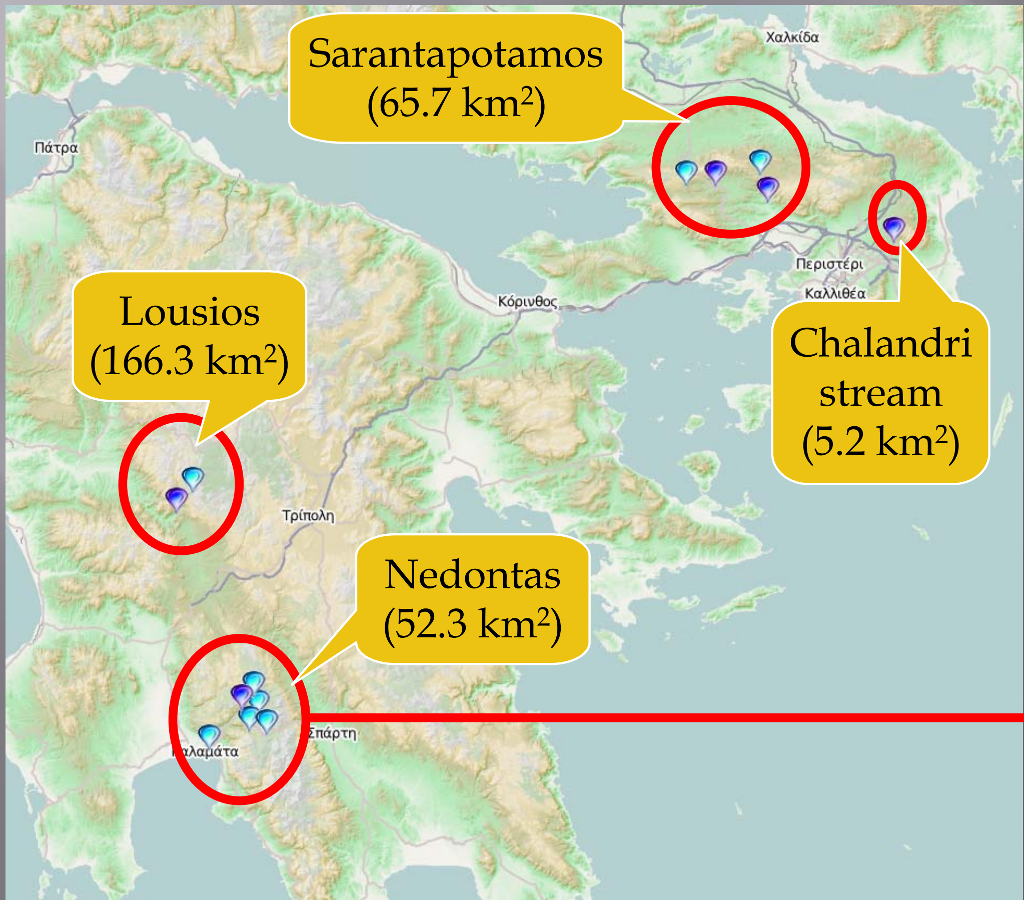
Flood forecast & risk assessment

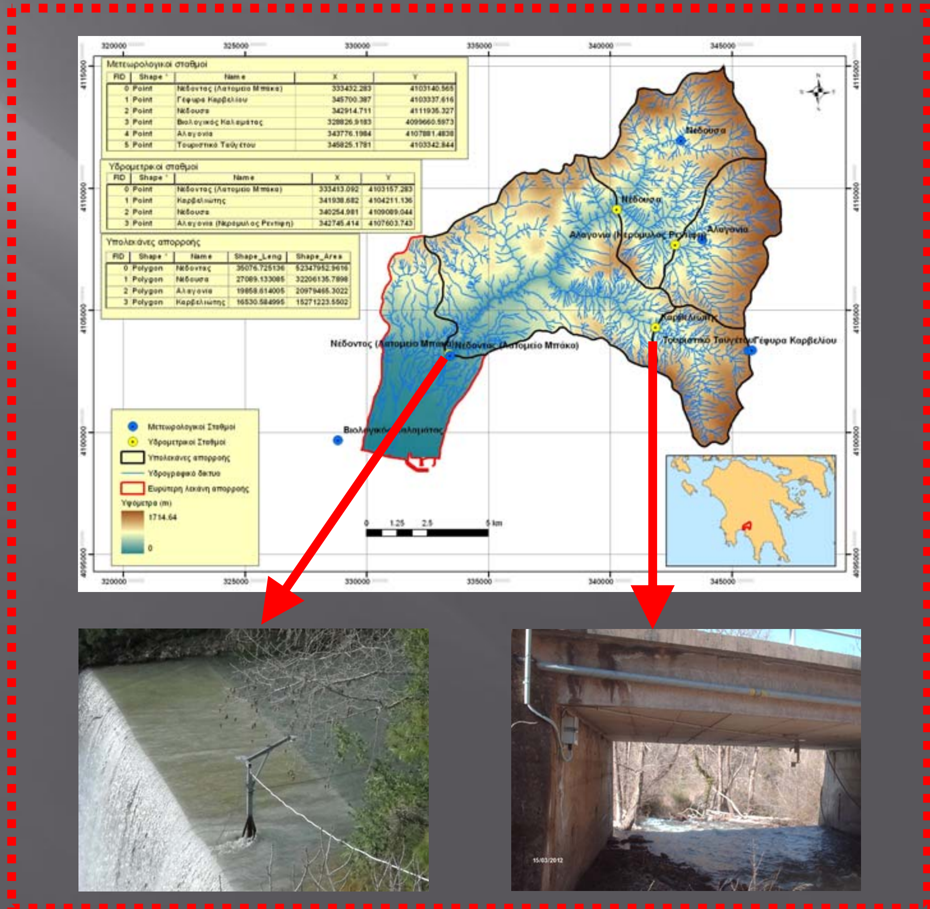
WP6: Technical specifications for flood studies

Design criteria and methods ⟷ Public debate & consultation

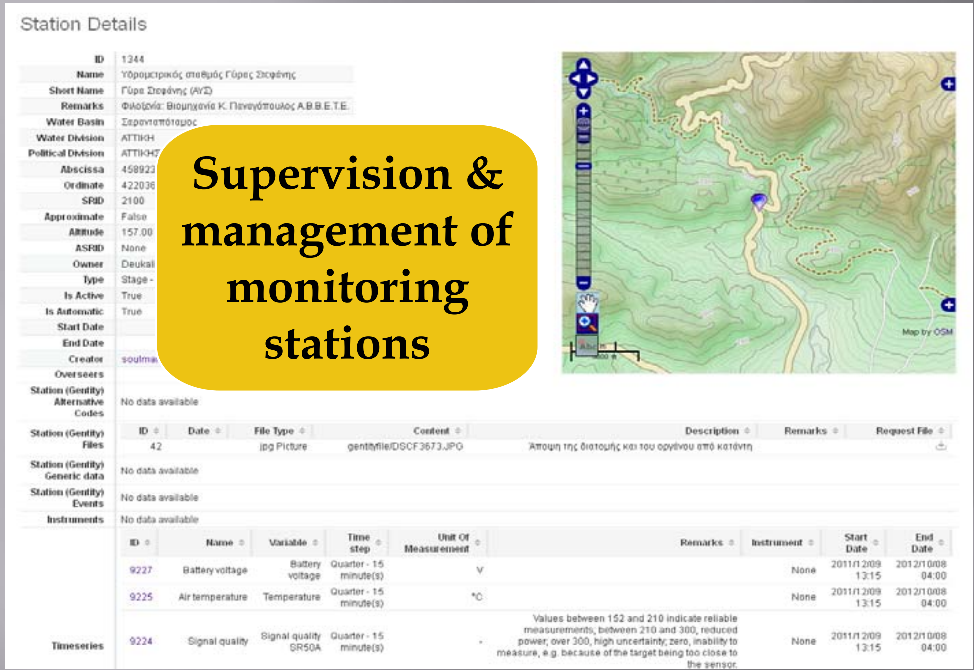
Pilot basins, monitoring network & data

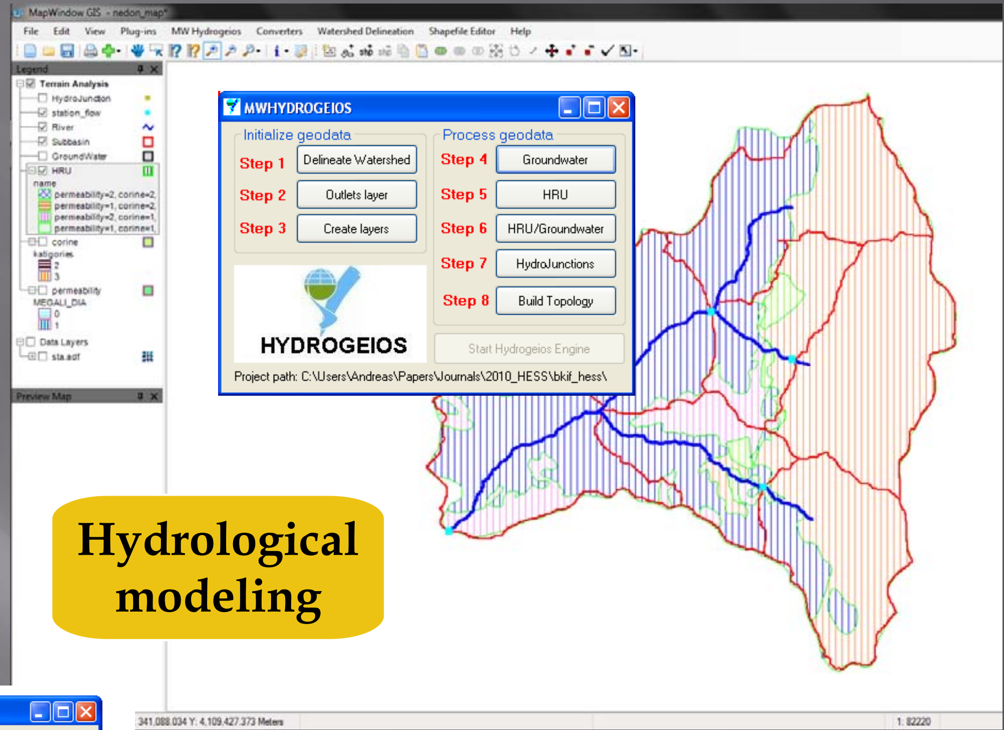
- Development of 4 pilot basins, with 8 stage recording & 10 meteorological stations, and an open-source application, to visualize and provide online data (http://openmeteo.org/).
- Further data were obtained from Cyprus basins, with long and reliable records, and an experimental basin in Greece.

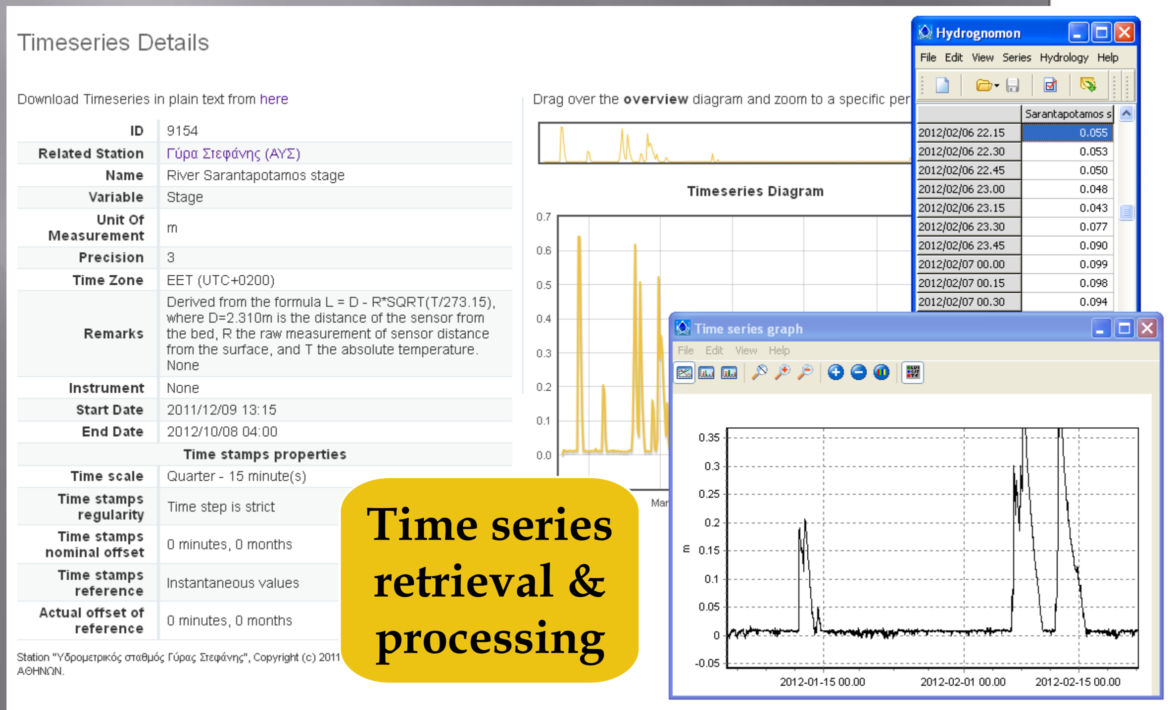


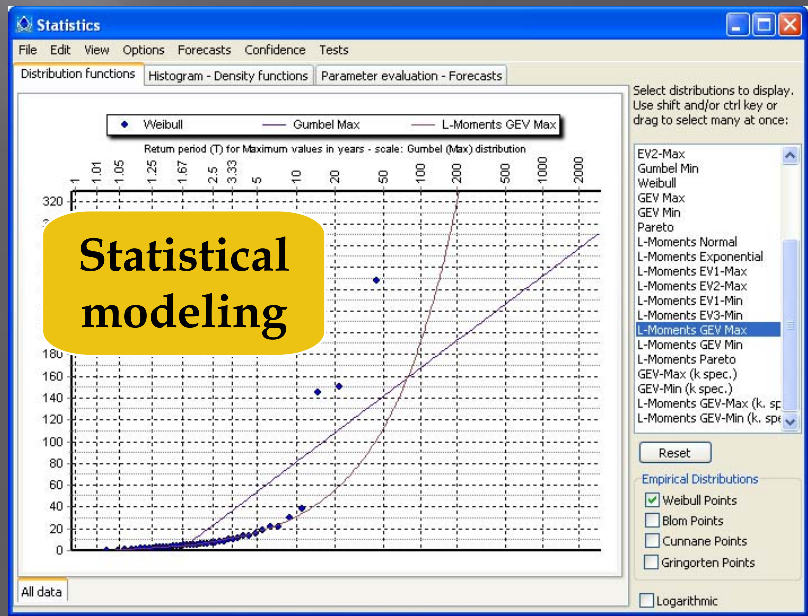


Software & models



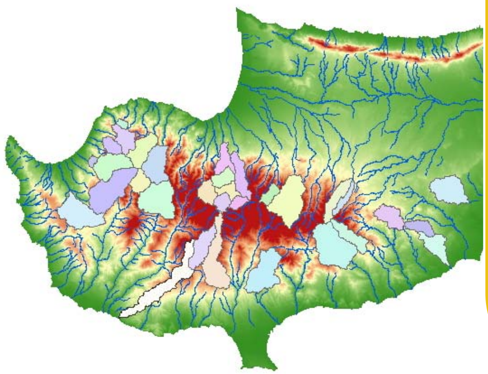




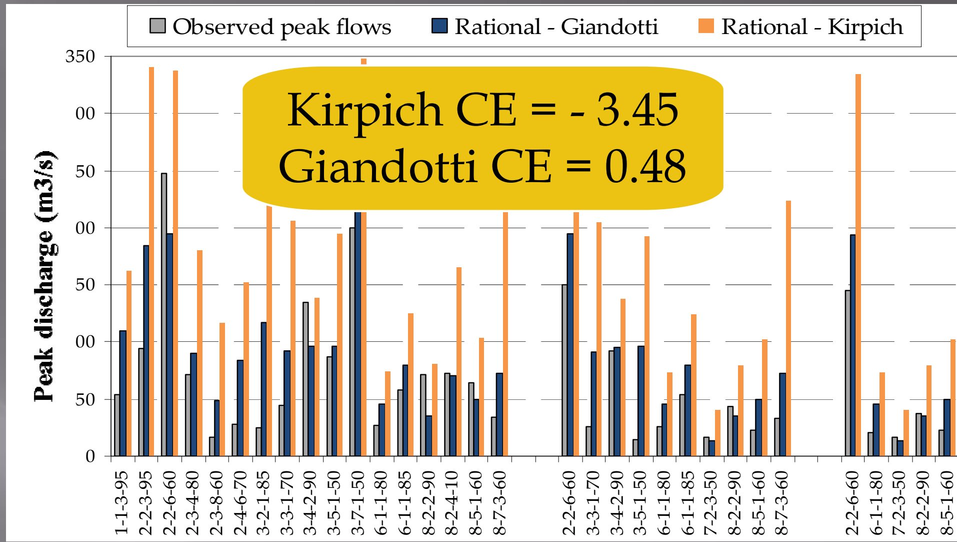


Research task 1: Evaluation of rational method & t_c formulas in Cyprus

Study basins



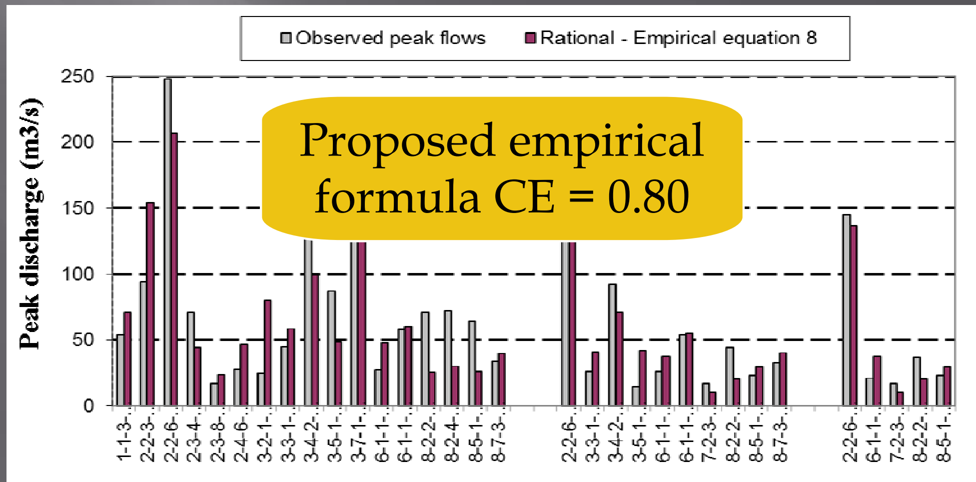
Statistical analysis of annual flow maxima, reproduction of peaks with rational method, using the idf curve and standard runoff coefficients (Galiouna *et al.*, 2011)



Kirpich CE = - 3.45
Giandotti CE = 0.48

Description	Time of concentration	Runoff Coefficient	CE
Empirical Equation 1	$t_c = \frac{L}{3600 \quad u} \quad u = 2{,}22 m/s$	Regulations OMOE	-0.170
Empirical Equation 2	$t_c = \frac{L}{3600 \quad u} \quad u = 7.51\sqrt{S_{\max}}$	Regulations OMOE	-0.290
Empirical Equation 3	$t_c = 0.617\sqrt{A}$	Regulations OMOE	0.727
Empirical Equation 4	$t_c = \frac{5.0 A^{0.47}}{L_{\max}{}^{0.73}}$	Regulations OMOE	0.798
Empirical Equation 5	$t_c = \frac{3.59 A^{0.416}}{L^{0.494}} \quad t_c(T) = \frac{t_c}{T^{0.07}}$	Regulations OMOE	0.799
Empirical Equation 6	$t_c = \frac{121.76(A/L_{\max})^{0.396}}{60 S^{0.01}} \quad t_c(T) = \frac{t_c}{T^{0.2}}$	$c' = 0.5c$	0.790
Empirical Equation 7	$t_c = \frac{3.74(A/L_{\max})^{0.268}}{\sqrt{S} * CN^{0.429}} \quad t_c(T) = \frac{t_c}{T^{0.2}}$	$c' = 0.5c$	0.760
Empirical Equation 8	$t_c = \frac{4.23(A/L_{\max})^{0.429}}{\sqrt{S_{mean}} * CN^{0.29}} \quad t_c(T) = \frac{t_c}{T^{0.02}}$	$c(T) = 0.43c + 0.1\ln(T)$	0.797

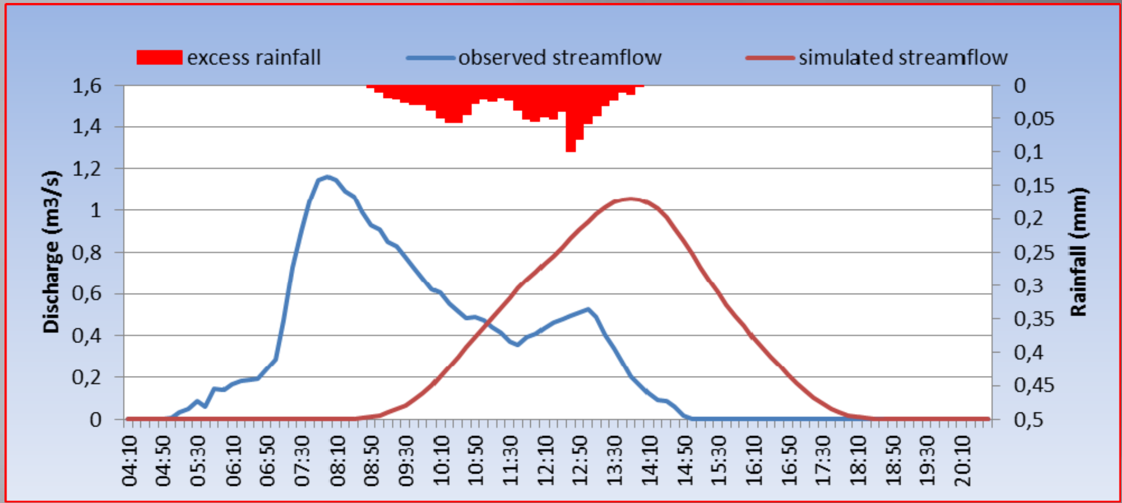
Evaluation of alternative regional formulas for time of concentration



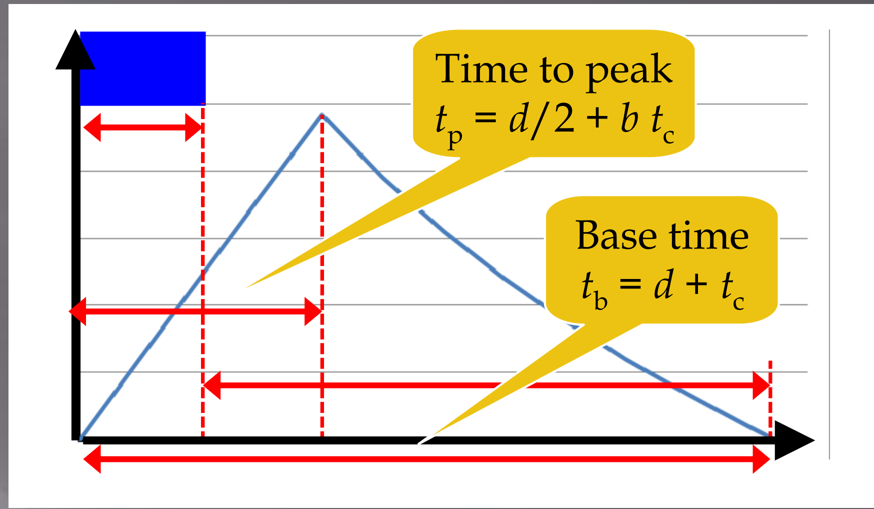
Proposed empirical formula CE = 0.80

Observed vs. simulated peak flows using the Giandotti & Kirpich methods (up), and the recommended empirical formula (down)

Research task 2: Evaluation of SCS-CN & synthetic UH approach in Lykorema basin



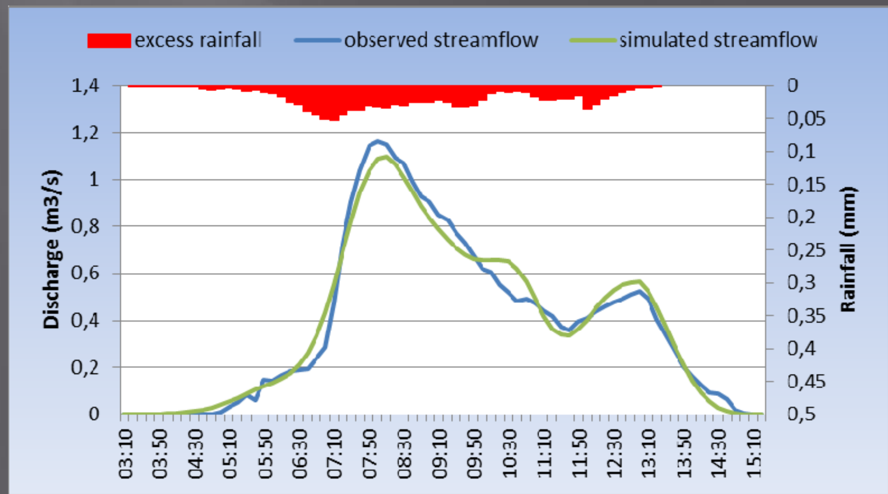
Typical values for a (initial abstraction ratio) & CN, SUH by the British Hydrological Institute



Empirical parametric SUH, with a single parameter, related to peak time

You are kindly invited to attend the presentation (Thursday, 16:50-17:10):

Mathioudaki, M., A. Efstratiadis, & N. Mamassis, Investigation of hydrological design practices based on historical flood events in an experimental basin of Greece (Lykorema, Penteli)



Hydrograph fitting against a, CN & b

Conclusions

- Flood design recipes vs. reality
  - Flood studies are much more than blind applications of "recipes";
  - When studies are treated as recipes, they probably provide results far from reality (which cost a lot, in terms of money or risk);
- Can predictions for ungauged basins be trusted?
  - It is impossible to answer, if predictions are not validated at the local scale;
  - It is impossible to make validations, before employing extended, systematic and reliable measurements.
- A perspective from Greece
  - Ongoing research on flood modeling within Deukalion project already provided encouraging outcomes;
  - Attempts are also made by other research institutions in Greece;
  - The key challenge for academic hydrologists is to transfer their knowledge to the everyday engineering practice.

References

Galiouna, E., A. Efstratiadis, N. Mamassis, and K. Aristeidou, Investigation of extreme flows in Cyprus: empirical formulas and regionalization approaches for peak flow estimation, *EGU General Assembly 2011, Geophysical Research Abstracts, Vol. 13*, Vienna, 2077, 2011.

Grimaldi, S., A. Petroseli, F. Tauro, and M. Porfiri, Time of concentration: a paradox in modern hydrology, *Hydrological Sciences Journal*, 57(2), 217–228, 2012.

Kirpich, Z.P., Time of concentration of small agricultural watersheds, *Civil Engineering*, 10(6), 362, 1940.

Koutsoyiannis, D., *Design of Urban Sewer Networks*, Edition 4, 180 pages, National Technical University of Athens, Athens, 2011 (in Greek; http://itia.ntua.gr/en/docinfo/123/).

Koutsoyiannis, D., Reconciling hydrology with engineering, *IDRA 2012 – XXXIII Conference of Hydraulics and Hydraulic Engineering*, Opening lecture, Brescia, 2012 (http://itia.ntua.gr/en/docinfo/1235/).

Koutsoyiannis, D., Statistics of extremes and estimation of extreme rainfall, 2, Empirical investigation of long rainfall records, *Hydrological Sciences Journal*, 49(4), 591–610, 2004.

McCuen, R.H., Uncertainty analyses of watershed time parameters, *Journal of Hydrologic Engineering*, 14(5), 490–498, 2009.

Mulvany, T.J., On the use of self registering rain and flow gauges, *Proceedings Institute Civil Engineers*, 4(2), 1–8, 1850.

Papalexiou, S.M., D. Koutsoyiannis, and C. Makropoulos, How extreme is extreme? An assessment of daily rainfall distribution tails, *Hydrology and Earth System Sciences Discussions*, 9, 5757–5778, 2012.

U.K. National Environmental Research Council, *Flood Studies Report*, Institute of Hydrology, Wallingford, 1975.

Veneziano, D., and A. Langousis, The areal reduction factor: A multifractal analysis, *Water Resources Research*, 41, doi:10.1029/2004WR003765, 2005.

This presentation is available on-line at:

http://itia.ntua.gr/en/docinfo/1291/

Deucalion project web site:

http://deucalionproject.gr/

Contact info:

andreas@itia.ntua.gr

akoussis@noa.gr