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Session title: "Natural Hazards - Floods & Seismic"

Hydro-meteorological network for flood monitoring and modeling

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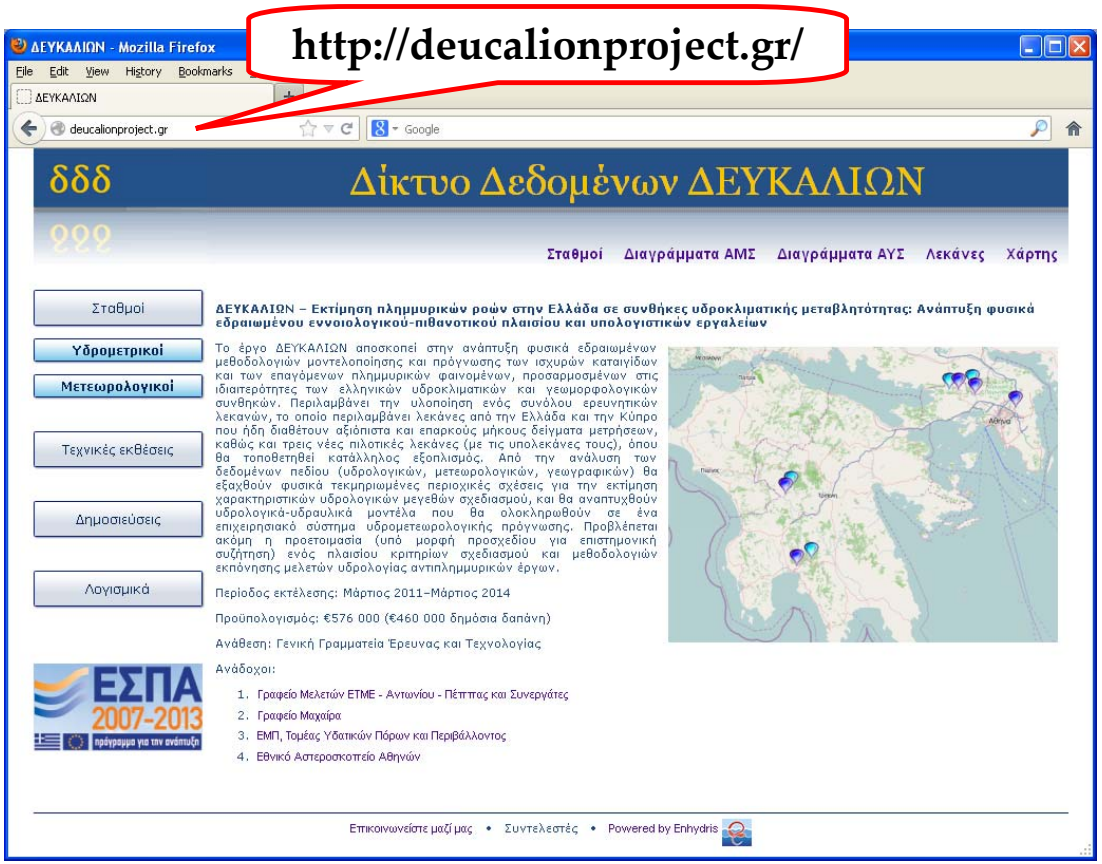
1. Introduction & motivation

- There exist hundreds of small- to medium-size (i.e. up to ~250 km^2) Mediterranean basins (particularly in Greece and Cyprus), which are typically affected by **flash floods**.
- The majority of them lack measuring infrastructure (especially, continuous flow-gauging stations), which is essential for both **flood monitoring** and **modeling**.
- Due to the lack of flow information are preferred rather simplistic or outdated approaches for **ungauged basins**, with questionable physical consistency, since most of them do not consider local peculiarities (hydroclimatic, geomorphological).
- In order to provide a consistent framework for flood design and to ensure realistic predictions of the flood risk, which is key issue of the **2007/60/EC Directive**, it is crucial to improve the monitoring infrastructures, by taking advantage of modern technologies for remote control and data management.
- In this context, we have recently developed a **telemetry-based hydro-meteorological network** that comprises automatic stations in four pilot river basins, which is linked to and supported by relevant software.
- The **software system** includes:
  - a web-based application for storage, visualization and management of spatial and hydro-meteorological information (ENHYDRIS);
  - a software for hydro-meteorological data analysis and processing (HYDROGNOMON);
  - a modeling framework for flood simulation (HYDROGEIOS).
- The system is tested within a demonstration **case study**, implemented in one of the pilot river basins (Nedontas, Peloponnese).

2. The research program "Deucalion"

- **Full title**: Assessment of flood flows in Greece under conditions of hydroclimatic variability: Development of physically-established conceptual-probabilistic framework and computational tools
- **Partnerships**: (1) ETME Peppas & Collaborators S.A.; (2) Maheras Technical Office S.A., (3) National Technical University of Athens; and (4) National Observatory of Athens



WP1: Pilot river basins & monitoring network

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WP2: Data processing tools (hydro-meteorological & geographical information)

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WP3: Flood modeling tools (methodologies & software)

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WP4: Flood forecasting (coupling of meteorological, hydrological and hydraulic models)

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WP5: Assessment of methods (back analysis of hydraulic studies, using updated methods)

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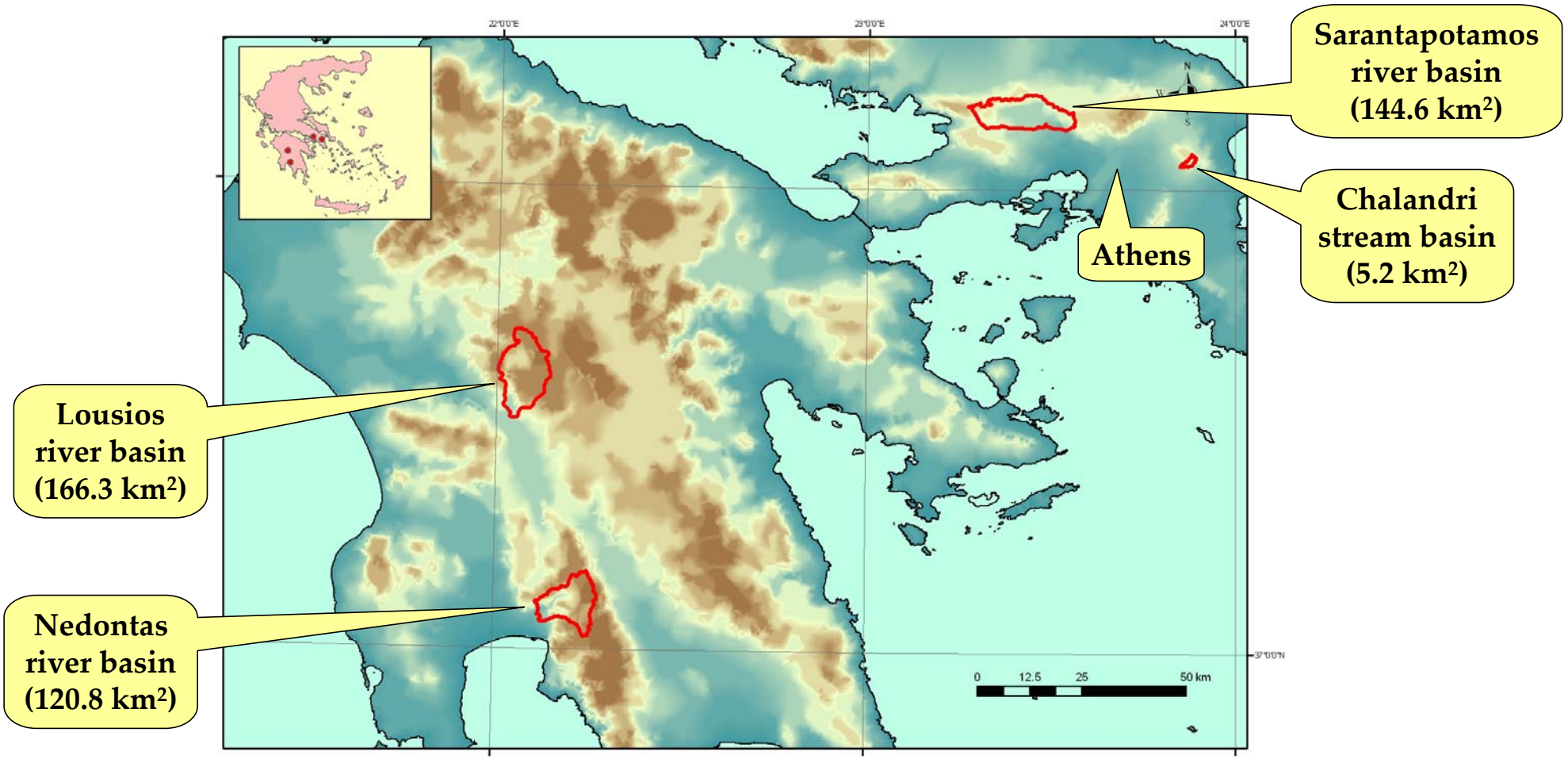
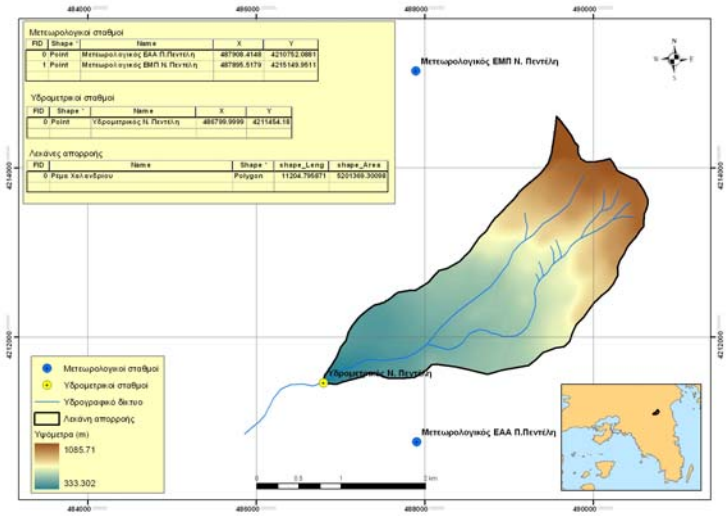
WP6: Technical specifications for flood studies in Greece

3. Telemetry-based monitoring network

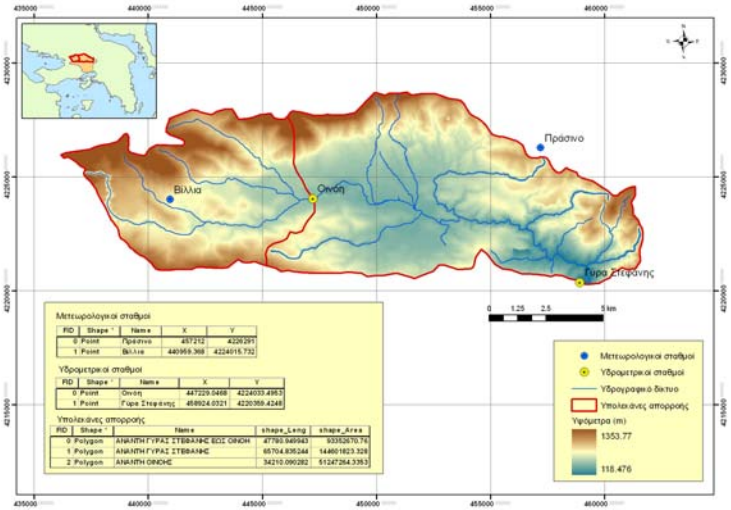
- **Network components**: 10 fully-equipped meteorological stations, 5 rain gauge stations, 8 automatic hydrometric stations
- **Spatial extent**: Four pilot river basins (two in Attica-Boeotia and two in Peloponnese), with areas ranging from 5.2 to 166.3 km^2
- **Key specifications**: Automatic operation, low cost, reliability, preset time intervals, data logging, remote accessibility



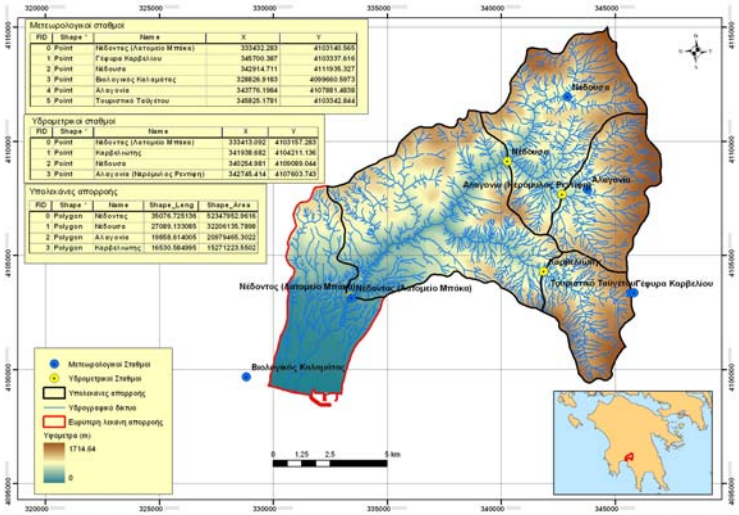
4. Basin characteristics



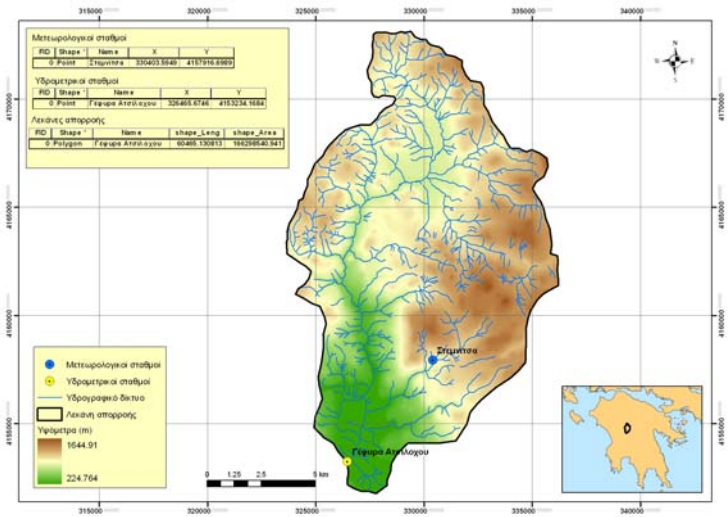
Chalandri stream: small-scale, sub-urban



Sarantapotamos: very low surface runoff, ephemeral flow, outflow to industrial zone



Nedontas: heterogeneity of soil permeability, permanent flow for 9-10 months, infiltration losses, outflow to urban area (Kalamata)



Lousios: high altitude, permanent runoff, significant contribution of baseflow (produced by an extended karst system), snowmelt

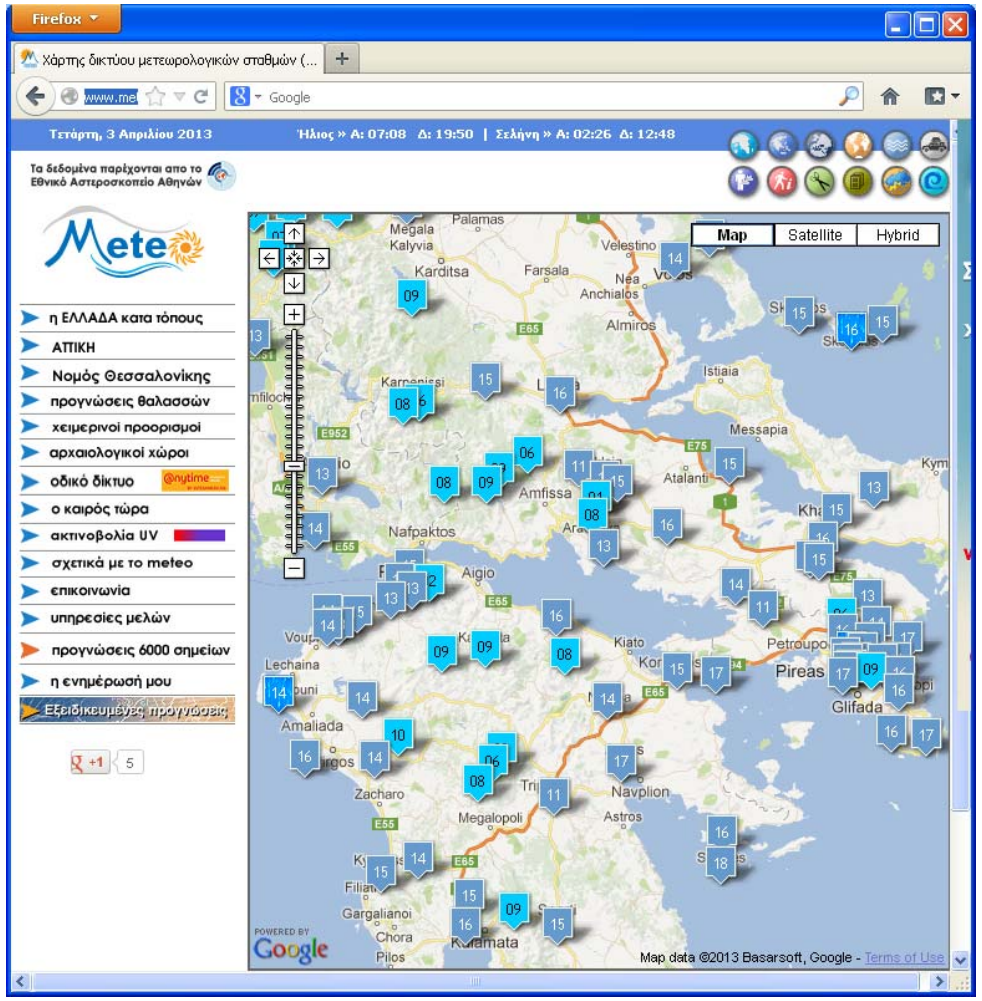
5. Monitoring infrastructure: flow stations

- For the installation of hydrometric stations, we took care to find cross-sections with stable geometry (e.g. bridges).
- When possible, we used existing manmade drops in the streambed that act as hydraulic controls, thus facilitating the indirect determination of discharge from stage measurements.
- All but one stations measure river stage, using 50-kHz ultrasonic pulses or piezometric sensors; stage measurements are always temperature-corrected.
- Particularly in Lousios, both stage and velocity are measured via an acoustic Doppler radar.
- 20-W photovoltaic panels feed the battery of each station.
- Data transfer is made via GPRS or mobile telephony.
- Data is recorded in 15-minute intervals and local storage capacity is provided for three-month data.

6. Monitoring infrastructure: meteorological stations

- 15 automatic meteorological stations have been installed in the context of Deucalion project, so as to provide good rainfall coverage over the pilot basins.
- All stations record precipitation, while ten of them also record air temperature, pressure, relative humidity, wind speed and wind direction (full meteorological data are essential for estimating evapotranspiration).
- These are part of a broader network of about 200 meteorological stations over Greece that are operated by volunteers, under the supervision of the National Observatory of Athens (www.meteo.gr/).
- Data are recorded in 10-minute intervals and are also logged locally for 17 days.

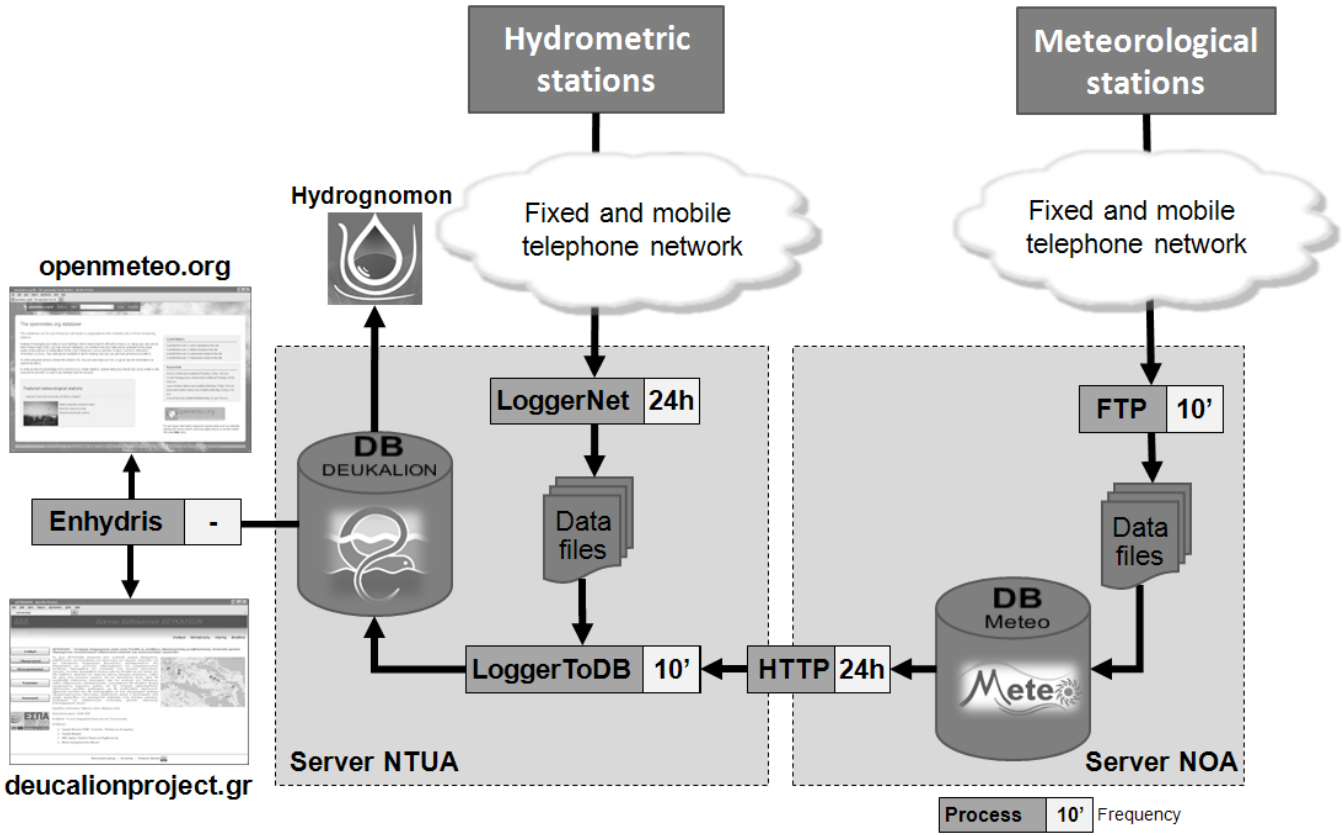
Meteorological station at Vilia (upper Sarantapotamos basin)



Web page of NOA, indicating the current air temperature values at 3/4/2013 10:00 am (www.meteo.gr/)

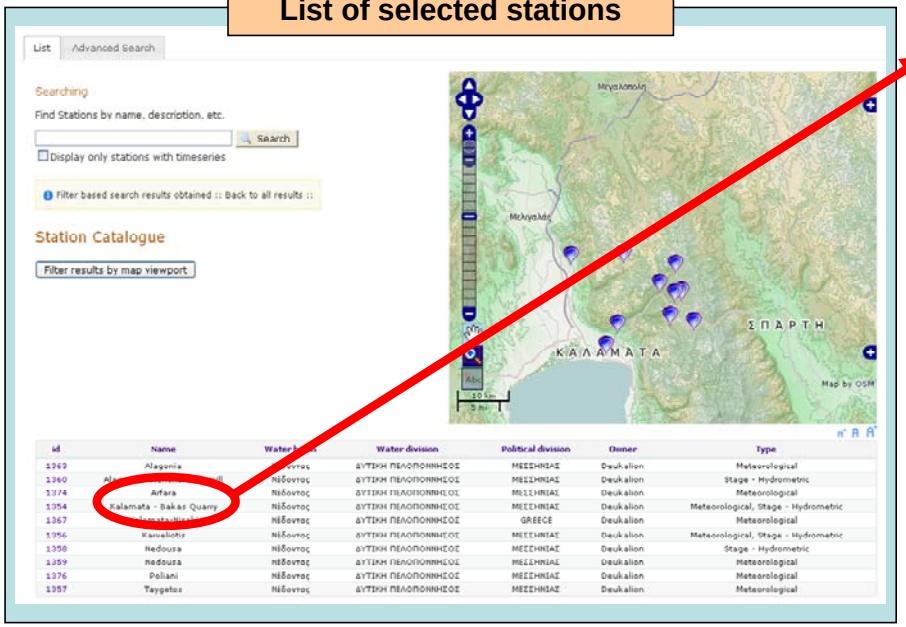
7. Data transfer, storage, processing & visualization

- The soft component of the network comprise a web application for supervision and management of monitoring stations and other geographical entities (**ENHYDRIS**), which is supported by a time series processing tool (**HYDROGNOMON**).
- Data are typically provided in form of text files with various formats, which are next homogenized through a specific application (LoggerToDB).
- The data are published to the web site of the project (deucalionproject.gr) as well as the openmeteo.org site; the latter is an **open source** initiative, devoted to the distribution of free hydrometeorological data and software worldwide (Kozanis *et al.*, 2011).

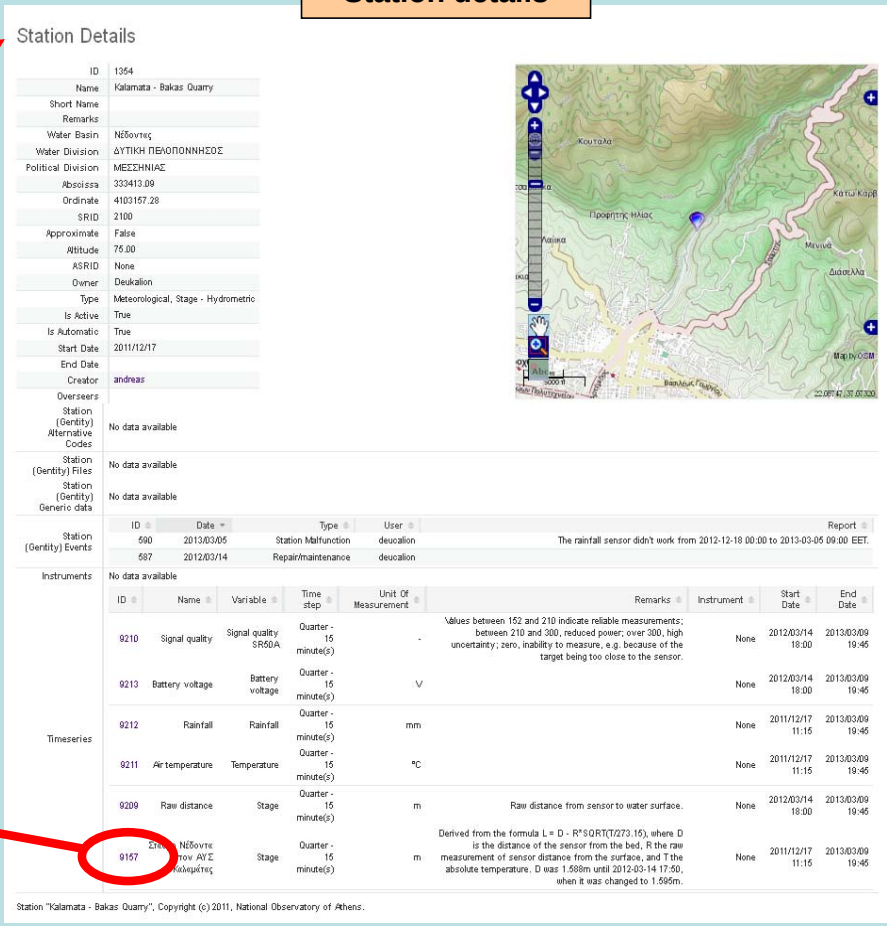


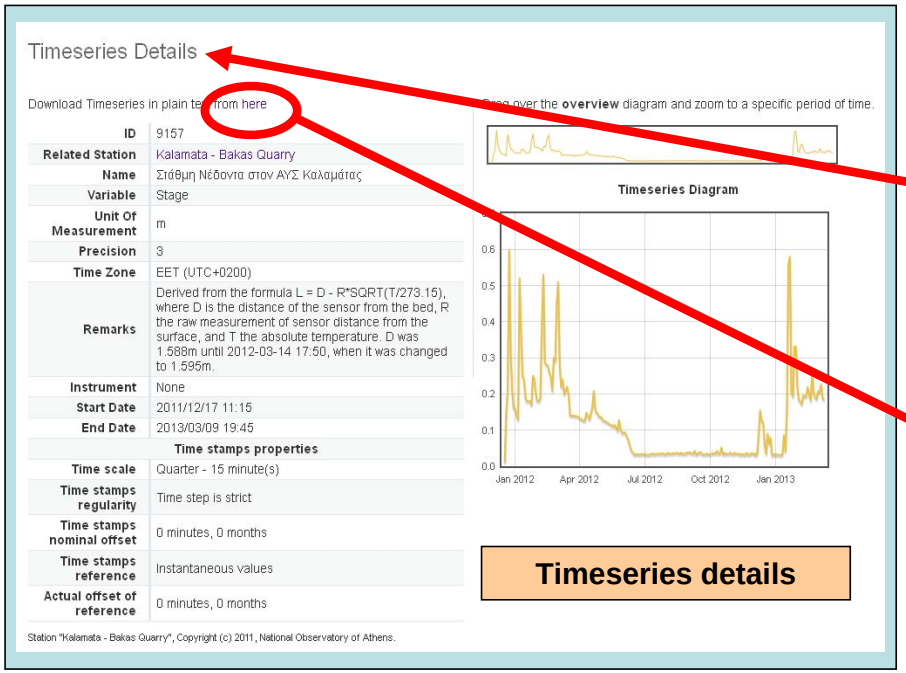
8. The web platform (Enhydris & Hydrognomon)

List of selected stations

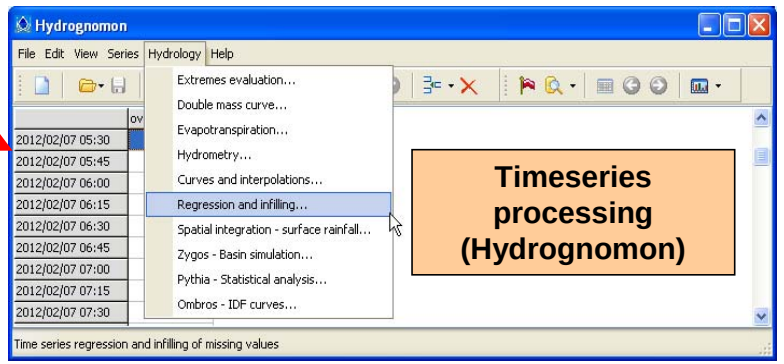


Station details





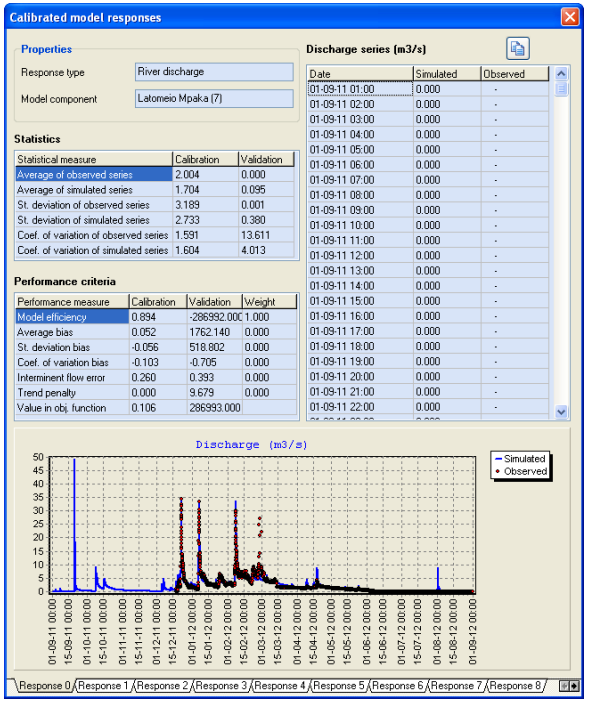
Timeseries details

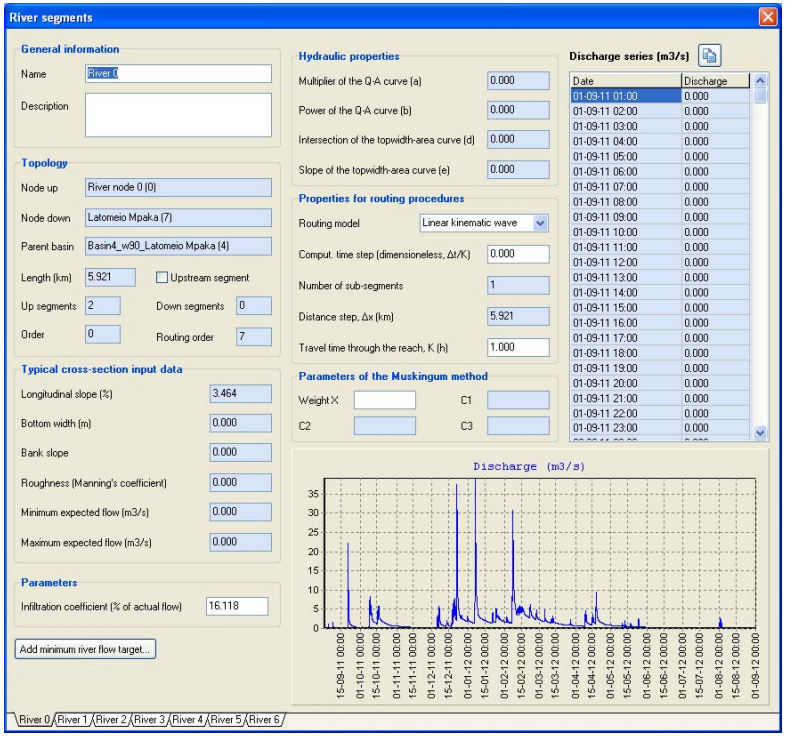


Timeseries processing (Hydrognomon)

9. Sample flood modeling application

- A key objective of Deucalion project is the development of **continuous simulation models** for the representation of flood flows across hydrographic networks of any complexity.
- Continuous simulation is essential for properly interpreting **flood risk** as joint probabilities of all hydrological variables that interrelate in runoff generation (rainfall, soil moisture).
- We used as basis the **HYDROGEIOS** software, initially oriented to water management problems in modified river basins, for which monthly simulations are adequate (Efstratiadis *et al.*, 2008; Nalbantis *et al.*, 2011).
- The software was enhanced and improved to also support **daily and hourly time steps**, thus being suitable for the representation of flood processes.
- The new version of HYDROGEIOS was evaluated in the **river basin of Nedontas**, and its performance was contrasted to the well-known HEC-HMS software (Zogakis, 2013).
- The simulation period for model testing was a full hydrological year (1/9/2011 to 31/8/2012), for which we aimed to reproduce the observed hourly flows at the **three measuring stations** (Nedontas outlet, Alagonia, Karveliotis).



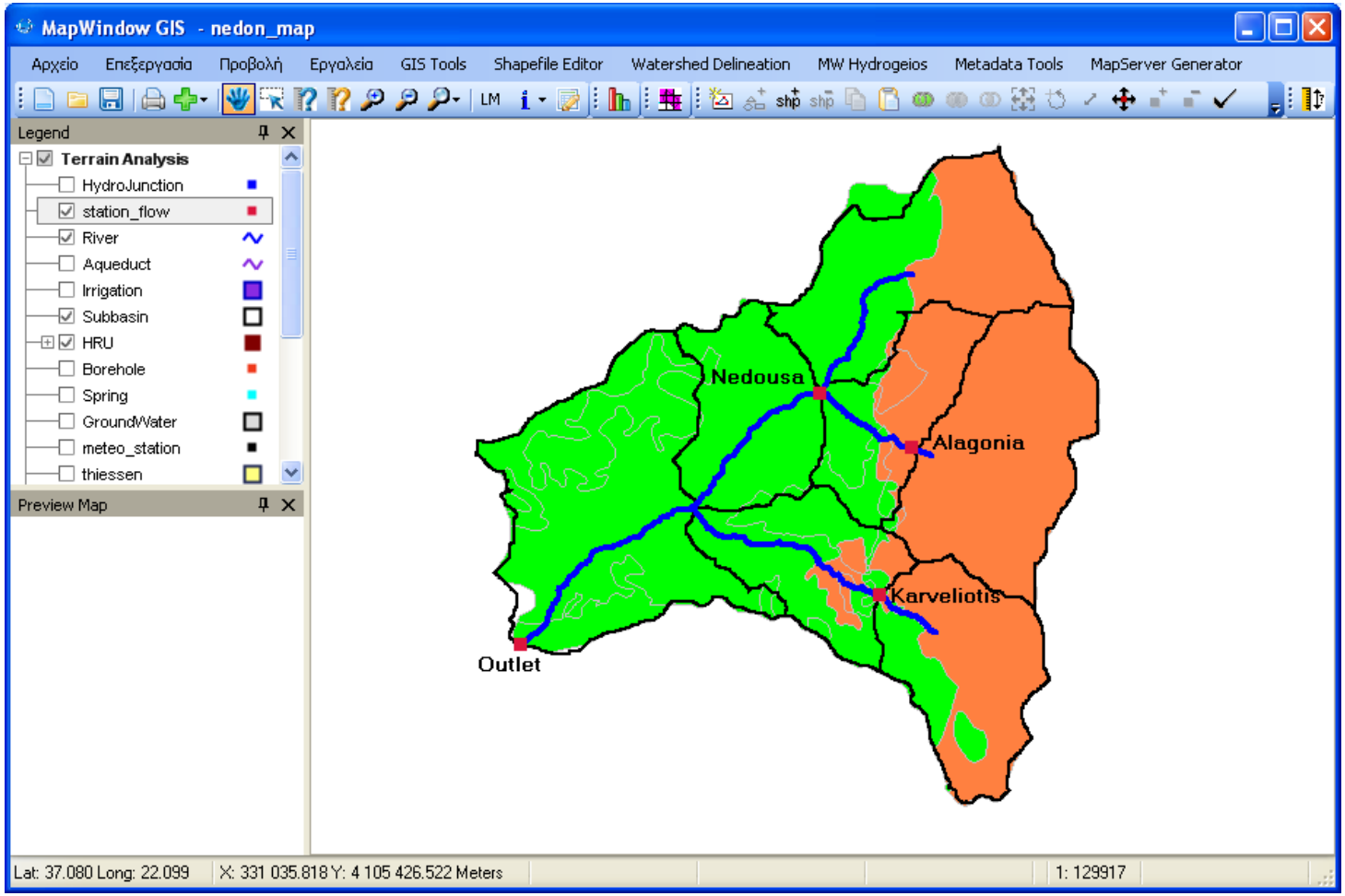


10. The HYDROGEIOS modeling system

- **Rainfall-runoff module**
  - Semi-distributed schematization of the surface hydrological system (river network, sub-basins);
  - Conceptualization through interconnected tanks that represent the key hydrological processes on the ground and the unsaturated zone, using seven parameters;
  - Model parameters are considered homogeneous within Hydrological Response Units (HRUs), defined by the classification of properties such as permeability, land cover, terrain slope, etc.;
  - Model inputs: precipitation & potential evapotranspiration (PET) data, varying per sub-basin;
  - Model outputs: actual evapotranspiration, percolation, runoff.
- **Groundwater module**
  - Finite-volume approach (Rozos and Koutsoyiannis, 2006), aquifer discretization to few polygonal cells of flexible shape, Darcian representation of flow field;
  - Stress data: percolation, infiltration, pumping;
  - Model parameters: conductivities, specific yield;
  - Model outputs: groundwater level, baseflow (through springs), underground losses.
- **Water allocation & management module**
  - Network-type representation of water uses and main hydraulic structures;
  - Estimation of unknown flows and abstractions through linear optimization.
- **Routing module**
  - In-basin routing of hydrographs through a linear reservoir approach;
  - Propagation of hourly hydrographs along the river network through a kinematic-wave or a Muskingum diffusive-wave model, for steep and mild slopes, respectively (Koussis, 2009, 2010).

11. Geographical inputs (MapWindow environment)

- 7 sub-basins, 5 river nodes (hydrometric stations and junctions);
- 2 HRUs, assuming two permeability classes;
- one groundwater cell beneath each sub-basin;
- 4 springs, implementing the generation of baseflow;
- one dummy cell, accounting for underground losses.



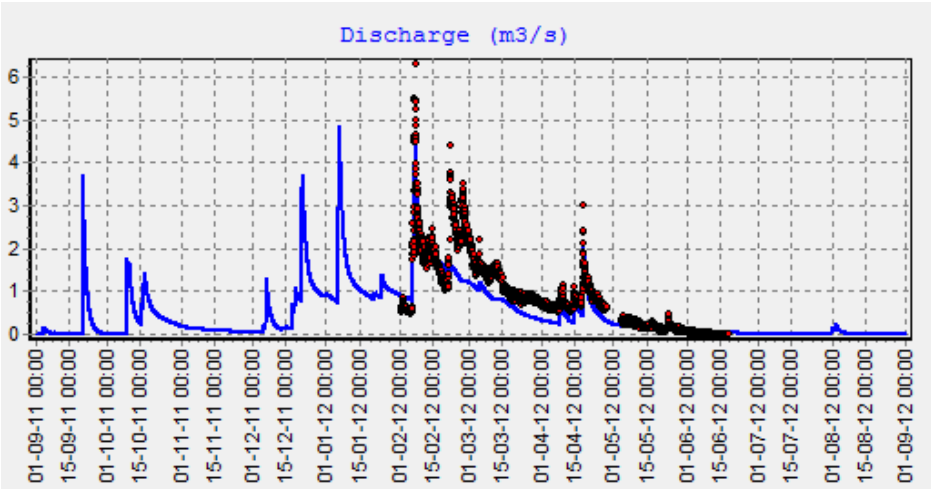
12. Input hydro-meteorological data

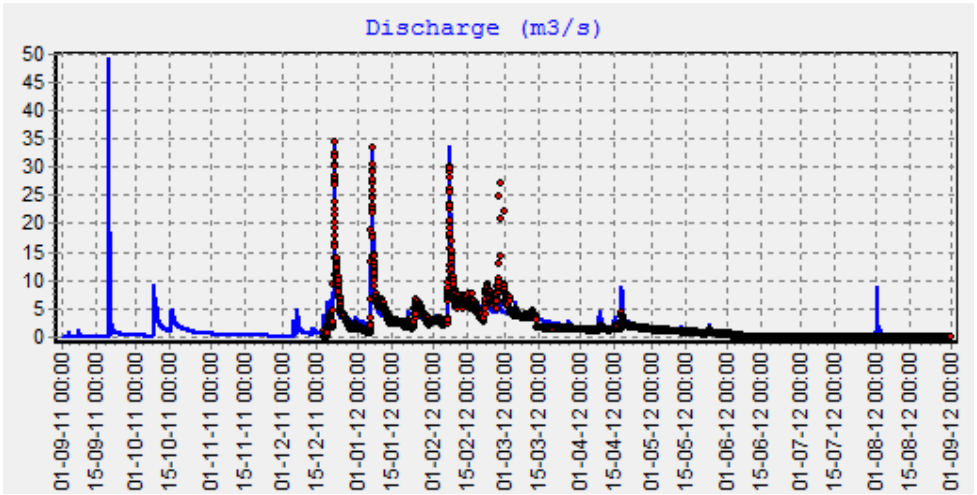
- **Rainfall time series**
  - Aggregation of 10-minute data records to hourly intervals;
  - Filling of missing values through linear regression analysis;
  - Areal integration through the Thiessen polygon method;
  - Adjustment to mean elevation of each sub-basin, assuming an annual rain slope of 0.75 mm/m.
- **Potential evapotranspiration (PET) time series**
  - Aggregation of 10-minute temperature records to daily and monthly intervals;
  - Use of a simplified expression of the Penman-Monteith formula (Tegos *et al.*, 2013) for the estimation of monthly PET, on the basis of mean monthly temperature, extraterrestrial solar radiation and regional parameters that have been calibrated against local meteorological data;
  - Empirical disaggregation of monthly to daily PET, on the basis of daily temperature;
  - Elementary estimation of hourly PET.
- **Discharge time series**
  - Pre-processing of raw stage data (removal of negative values, adjustment to an offset stage);
  - Establishment of theoretical rating curves (i.e. stage-discharge relationships) to the three cross-sections, assumed that the measured stage corresponds to the critical flow depth;
  - Further analysis, based on the FLOW3D software, to better represent the high flows;
  - Calculation of instantaneous flows at 15-min intervals and estimation of mean hourly discharge through aggregation.

For the processing of raw hydro-meteorological data and the preparation of the input time series, we used the HYDROGNOMON software.

13. Model calibration

- Formulation of an weighted objective function, comprising two criteria:
  - Coefficients of efficiency at the three measuring stations (primal criterion);
  - Empirical measures (trend penalties), assigned to all cells, which ensures a "reasonable" representation of groundwater dynamics.
- Hybrid multicriteria calibration:
  - Automatic optimization of small sets of model parameters, employing the evolutionary annealing-simple method (Efstratiadis and Koutsoyiannis, 2002);
  - Manual guidance of search towards promising areas of the search space, taking advantage of hydrological experience;
  - Detection of a compromise parameter set, which exhibits satisfactory predictive capacity at all measured sites.
- Key results, in terms of efficiency: Alagonia = 0.77; Karveliotis = 0.59; outlet = 0.95





Simulated vs. observed hourly flows at Alagonia (left) and the outlet of Nedontas basin (right)

14. Conclusions & proposals for further research

- After two years of development and pilot testing, most of the system components (hard: monitoring network; soft: applications and models) are fully **operational**.
- The monitoring network can (and should be) expanded, to cover more basins, particularly those lying in potentially hazardous areas.
- The soft component, which has been implemented as **open-source** software, comprises general-purpose tools, which are applicable to a wide range of water resource problems.
- ENHYDRIS & HYDROGNOMON can effectively support the **supervision and management of hydrometeorological networks**, without restrictions to the number of users and the extent of data.
- The upgraded version of HYDROGEIOS, with parameters properly fitted to local data, ensures both **physical consistency** and **parsimony** in the representation of the hydrological processes, at fine time intervals.
- In next research steps, HYDROGEIOS will be integrated with other modules, i.e.:
  - a **rainfall generator**, providing synthetic rainfall time series to the hydrological model, in order to run in stochastic simulation mode, for the statistically consistent evaluation of flood risk within hydrological design studies;
  - a **hydraulic simulation** tool, to be employed within flood inundation studies;
  - a **numerical weather prediction** system, to evaluate the basin's response against ensembles of short-term rainfall data.

This presentation is available at http://itia.ntua.gr/en/docinfo/1329/

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