Assessing different levels of model complexity for the Liri-Garigliano catchment simulation (1)

EGU General Assembly 2011, Vienna, Austria, 3-8 April 2011

Session HS1.6: *Metrics and the Use of Data in Hydrology to Support Model Structure Improvement*

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1. Abstract

Using as example one of the most challenging hydrological systems in Italy, i.e. the Liri-Garigliano basin, we attempt to identify the role of the model complexity regarding its predictive capacity, subject to data availability. For the representation of the hydrological processes of the basin, four parameterization approaches are examined, through the modelling framework HYDROGEIOS. The first two approaches are restrained to the simulation of the rainfall-runoff and routing processes, whereas the next two take also into account the contribution of the aquifers to the hydrosystem operation. The simplest configuration follows a semi-lumped parameterization, thus assigning the same parameter values to all sub-basins. The next approach follows a distributed parameterization to account for the surface system heterogeneity, on the basis of the hydrological response unit (HRU) concept. In the third approach, a conceptual groundwater cell is introduced under individual sub-basins or clusters of neighbouring sub-basins. In this approach the groundwater cells are isolated, thus prohibiting any exchange of flow among them. This restriction is lifted in the last approach, which enables to selectively allow hydraulic connectivity among the groundwater cells; in addition, it introduces few peripheral cells to simulate groundwater leakages to adjacent aquifers and to the sea. Moving from the first to the second and then to the third parameterization, there is a substantial improvement of the model performance, as evaluated on the basis of the efficiencies of the observed hydrographs at six flow gauges. Nevertheless, the last approach, although providing similar efficiencies with the third one, is the only consistent one, since it ensures a realistic representation of both the surface and groundwater cycle. In the absence of further information, any attempt to increase the model complexity, would result to a non-parsimonious parameterization thus increasing the uncertainty of the model predictions.

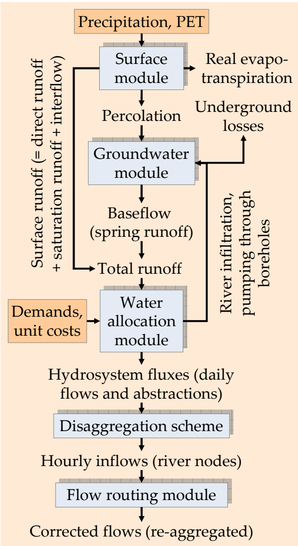
2. The HYDROGEIOS model

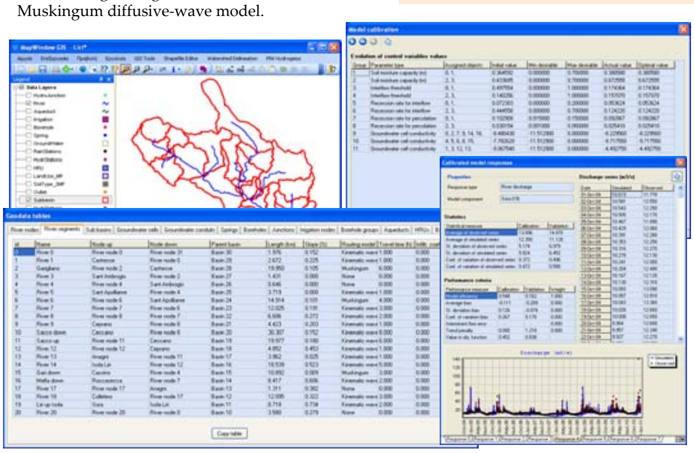
Surface hydrology module (daily time step)
- Semi-distributed schematization;
- Conceptualization through 3 interconnected tanks, representing the surface hydrological processes;
- Model inputs: daily precipitation and potential precipitation (PET) data, varying per sub-basin;
- Model parameters: 7 per hydrological response unit;
- Model outputs: evapotranspiration, percolation and runoff (directly transferred to the sub-basin outlet).

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 (aqueducts, boreholes, diversion projects);
- Step-by-step estimation of unknown flows and abstractions through a linear optimization approach, where artificial capacities and unit costs are imposed to preserve constraints and water use priorities.

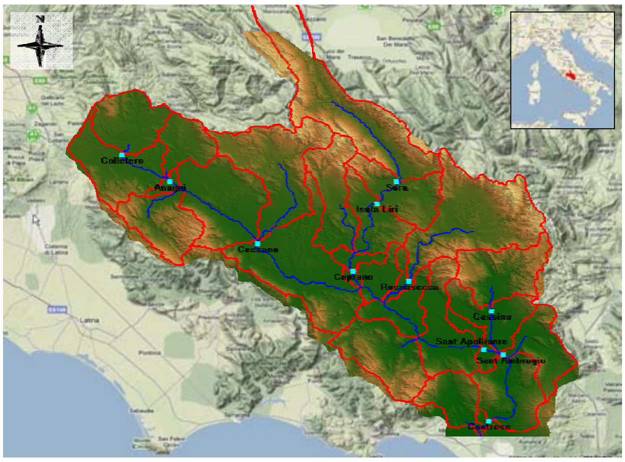
Flow routing module (hourly time step)
- Construction of hourly-resolved inflow hydrographs, through an empirical disaggregation scheme;
- Flow routing through a kinematic-wave or a Muskingum diffusive-wave model.





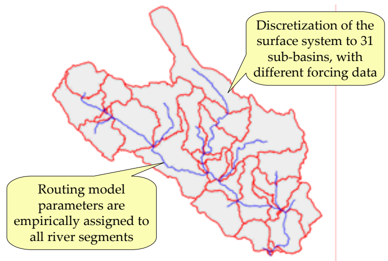
3. Description of the study area

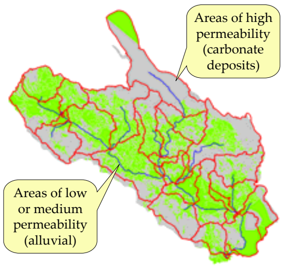
Liri is one of the principal rivers of central Italy, flowing into the Tyrrhenian Sea, under the name Garigliano. The Liri-Garigliano basin is one of the principal hydrological system rivers of central Italy is about 4900 km^2 and the length of the main course is 160 km. The hydrological system exhibits significant heterogeneity. The mountains located in the NE area and the Apennines are dominated by carbonate platform deposits that are intensively karstified. This part of the basin is characterised by high effective infiltration, poor development of the hydrographic network and low overland flow; most of runoff derives from karst springs of relatively stable flow regime. On the other hand, there are areas lying on geological formations of low permeability, the hydrological regime of which is characterized by significant overland flow from autumn to winter.



Layout of the study area, delineation of sub-basins and location of hydrometric stations

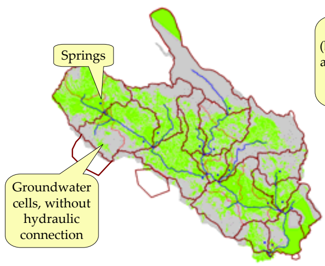
4. Levels of model schematization and parameterization

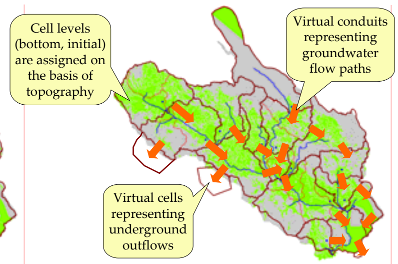




Level A: Semi-lumped approach, different forcing data (i.e., precipitation and PET) per sub-basin, same parameter values for the entire system (7 parameters)

Level B: Semi-distributed approach, formulation of hydrological response units on the basis of two permeability classes, to which different parameters values are assigned (7 × 2 = 14 parameters)





Level C: Formulation of 15 isolated ground-water cells under each sub-basin, receiving the percolation from the overlaying areas to produce baseflow (14 +15 = 29 parameters)

Level D: Formulation of a coarse network of inter-connected cells to represent the groundwater flow field, including three virtual cells modelling under-ground losses (29 + 2 × 15 + 3 = 62 parameters)

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5. Input data for daily simulations

Geographical data

- Digital elevation model;
- Geological map, from which two soil permeability classes were formulated;
- Land use map, condensed into two major classes (forested areas, agricultural areas);

Raw hydrological data (2002-2010)

- Daily precipitation at 11 rain gauges;
- Mean daily temperature at 8 meteorological stations;
- River level observations at 13 flow stations;
- Rating curves, calculated through the HEC-RAS software;

Processed hydrological data (model inputs)

- Areal precipitation, spatially aggregated using the Thiessen method and adjusted to the mean elevation of each sub-basin, applying an annual rain slope of 0.55 mm/m;
- Potential evapotranspiration (constant mean monthly values were assumed for the entire basin and the entire period);
- Daily discharge data downstream of all hydrometric stations;

➢ A preliminary analysis, based on the evaluation of the annual runoff coefficients, indicated that only 6 out of 13 stations have reliable data, to be considered in calibrations.

Acknowledgments: All data were provided by the "Ufficio Idrografico e Mareografico della Regione Lazio"

6. Parameter estimation through multi-criteria calibration

- ➢ Increasing the complexity of the model structure allows for a more faithful representation of the hydrological processes and their heterogeneity, which however requires more parameters to be estimated on the basis of the same amount of information.
- ➢ Regarding the surface system, the observed daily flow data at the six hydrometric stations is sufficient for a reliable calibration of the parameters that are assigned to the two soil permeability classes (i.e. hydrological response units).
- ➢ The reproduction of the baseflow, which is a key component of the hydrological regime of the basin, is ensured through appropriate calibration of the spring conductances, i.e. by fitting the simulated spring discharges to the low flow parts of the hydrographs.
- ➢ Due to the lack of information for the groundwater dynamics (spring flows, piezometric data), it is highly uncertain to estimate individual specific yield and hydraulic conductivity values for the 15 cells; for this reason, we employed a zonation approach, assuming a single value of specific yield for the entire aquifer and three conductivity values, assigned to groups of cells.
- ➢ For the last and most complex configuration, a weighted objective function was formulated, comprising the following components:
  - Efficiency of the daily hydrographs downstream of the six control stations (San Castrese, Sant' Apollinare, Sora, Anagni, Cassino, Ceccano), from 1/10/2004 to 31/12/2006;
  - Bias of the daily hydrographs at San Castrese (close to the basin outlet) and Sant' Apollinare;
  - Penalties for prohibiting erroneous interruption of the spring flows, in cases of permanent generation of baseflow, as shown in the related observed hydrographs;
  - Penalties for generating unrealistic rising or falling trends of groundwater levels.
- ➢ The last component is an empirical criterion that is essential in groundwater model calibration, since it prohibits systematic drainages and fillings of cells, in the vicinity of which there are not available spring flow or groundwater level observations.
- ➢ For the multiple levels of complexity, the folllo9ig efficiency values are obtained at the six control stations, for the calibration and validation periods:

Hydrometric	Calibration (1/10/04-31/12/06)				Validation (1/1/07-31/12/10)			
station	Level A	Level B	Level C	Level D	Level A	Level B	Level C	Level D
San Castrese	0.207	0.601	0.548	0.605	-0.068	-0.138	-0.031	-0.046
Sant' Apollinare	0.097	0.214	0.325	0.394	-0.045	-0.389	-0.112	-0.066
Sora	-1.181	-1.698	0.610	0.597	-0.736	-0.831	0.377	0.252
Anagni	0.161	0.695	0.684	0.686	0.083	0.290	0.224	0.208
Cassino	0.002	0.325	0.545	0.589	-0.168	-0.072	0.119	0.310
Ceccano	0.074	0.515	0.571	0.589	-0.282	0.124	0.306	0.411

Read more about the HYDROGEIOS model and its calibration strategy

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- Nalbantis, I., A. Efstratiadis, E. Rozos, M. Kopsiafti, & D. Koutsoyiannis, Holistic versus monomeric strategies for hydrological modelling of human-modified hydrosystems, *Hydrol. Earth Sys. Sci.*, 15, 743-758, 2011.
- Rozos, E., & D. Koutsoyiannis, A multicell karstic aquifer model with alternative flow equations, *J. Hydrol.*, 325(1-4), 340-355, 2006.
- Rozos, E., & D. Koutsoyiannis, Error analysis of a multi-cell groundwater model, *J. Hydrol.*, 392(1-2), 22-30, 2010.

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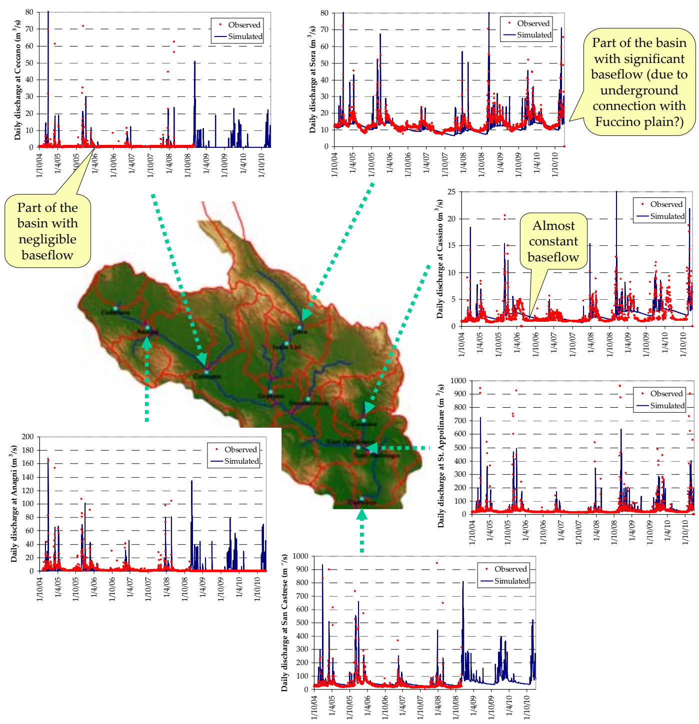
The presentation is available online at http://www.itia.ntua.gr/en/docinfo/1118/

The HYDROGEIOS modelling framework, including the input data for the Liri-Garigliano case study, are freely available for download at http://itia.ntua.gr/en/softinfo/25/

7. Simulated vs. observed hydrographs at the six flow control gauges



8. Conclusions and proposals for future research

➢ **General conclusions**

- Elaborated modelling of challenging hydrosystems, characterized by complex processes and restricted data, should be based, ideally, on flexible and expandable schemes, which allow increasing the level of detail in the processes representation, as further information arrives.
- Preliminary investigations are essential to establish the most suitable modelling structure (i.e. schematization and parameterization), which is at the same time physically-consistent, parsimonious and adaptable to the available knowledge.
- Under lack of hydrogeological information, a realistic simulation of the groundwater field is only effective through conceptual parsimonious models (i.e. multi-cell schemes), where the formulation of the corresponding groundwater network can be dictated by the delineation of the surface one (i.e. river network), while the spatial distribution of the baseflow can be used as a guide for the prevailing flow paths.

➢ **Site-specific conclusions**

- The Liri-Garigliano basin is a particularly complicated hydrological system, with significant heterogeneity and unusual allocation of its water resources, due to the domination of karst.
- The rainfall-runoff approach is certainly insufficient to represent the peculiarities of this system, although the transition from the lumped (level A) to the semi-distributed (level B) parameterization radically improved the efficiencies of some hydrographs.
- By introducing isolated cells under each sub-basin (level C), we obtained quite satisfactory efficiencies at all the control stations; however, this conceptual approach is far from reality, since the cells that should produce limited baseflow (according to the observed flow data) are forced to store the excess of percolation.
- The last configuration (level D), assuming a network of interconnected groundwater tanks, not only improved the model performance, but also ensured a realistic representation of the flow dynamics, thus allowing to establish a plausible and consistent water balance.

➢ **Issues to be accounted for in future research**

- Use of additional information within calibration, especially with regard to spring flow data.
- Representation of the possible interconnections, both surface and groundwater, of the Fuccino plain with the Liri-Garigliano basin.
- Representation of the human-modified status of the basin, accounting for the abstractions and the operation of the major hydraulic works, taking advantage of the water management component of HYDROGEIOS.