A hydrogeological acrostic: in honour of Ghislain de Marsily

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Geo-hydrological Data & Models

A hydrogeological acrostic: in honour of Ghislain de Marsily

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Great scientists are sometimes excessively modest, and ostentatious marks of appreciation may embarrass them. This special issue of *Comptes Rendus Géosciences* was initially thought as a hydrogeological firework launched by former students and current friends and colleagues of Professor Ghislain de Marsily to honour his multifaceted achievements and talents.

However, because we do not want to embarrass him more than strictly needed with our expressions of gratitude and admiration, we tried in this editorial to do so with as much discretion as we could. A recent biographical note by Simmons [2021] has already discussed the career, scientific contributions and international recognition of Ghislain de Marsily. These are not repeated here.

Inverse methods are the focus of several papers of this special issue: White and Lavenue [2023] review the *Pilot Point Method* for model inversion and uncertainty quantification, which has become a reference in the domain of inversion for groundwater modelling. Juda et al. [2023] compare several stochastic inversion methods, using a synthetic example (a pumping test in a fluvial channelized aquifer). Ackerer et al. [2023] discuss the difficulties that occur during the identification of aquifer heterogeneity using inverse methods and underline how seminal ideas introduced by Ghislain de Marsily helped address key inversion issues (stabilization of the inverse problem and parsimonious reproduction of the natural heterogeneity of the subsurface). Delay et al. [2023] also investigated the flow inversion issue, adopting a geophysical point of view with information produced by a seismic survey: they compare inverted hydraulic conductivity maps with the distribution of porous bodies identified by seismic data, and discuss the disappointing lack of a match. They end up questioning the idea of guiding conventional inversions with a geophysically-based prior guess of the subsurface structure.

Several papers deal with catchment-scale hydrology: Oudin and Lalonde [2023] present an attempt to parameterize the effect of land use within a "Budyko-type" hydrological formula. Using a worldwide set of more than 5000 catchments, they show a

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clear modulation of land use on evapotranspiration, suggesting larger and lower evaporation rates over croplands and urban areas respectively. Mathevet et al. [2023] present a diagnosis tool (a modification of the classical Taylor diagram) to analyze simulation results over large catchment sets to simultaneously visualize several error components. Kilic et al. [2023] presents an attempt to jointly model water and energy fluxes for the entire Seine catchment, both for surface- and groundwater.

Long-term observatories are also dealt with in this special issue: Chabaux et al. [2023] use the Strengbach Critical zone observatory (France), integrating petrological and hydrogeological information from boreholes and piezometers, to characterize water circulation channels at the catchment scale.

Aquifer properties are addressed in several of the papers: Dumont et al. [2023] present work on the Andesitic volcanic hydrosystems of Indonesia, using electrical resistivity tomography to characterize the aquifer and further parameterize the hydrological model structure. Malard et al. [2023] present a flow animation module (FAM) designed to increase the understanding of dynamic hydrogeological processes within a web-based modelling tool called Visual KARSYS. Jost et al. [2023] present their investigations relative to the link between gravel pit lakes and aquifers: they detail a gravel pit lake module developed for the CaWaQS modelling platform, which they test against the LAK package of Modflow.

In order to better understand how aquifers and rivers interact during extreme events, Pelletier and Andréassian [2023] study how yearly extremes of groundwater level and streamflow time series are related, using a large set of catchments and piezometers: the result is an aquifer typology, which distinguishes between aquifers that demonstrate correlations between groundwater level and streamflows only with high-flow events, only with low flows, with both types of events or with none of them.

New numerical approaches to characterize aquifers are investigated by Le Moine [2023], who presents a method for interpolating the elevation between talwegs using the Analytic Element Method and discusses a new index named *Height Above the Basal Envelope Surface of Talwegs (HABEST)* to characterize groundwater levels at catchment scale. Zimmer et al. [2023] present a retrospective analysis of the development of the theory of subsurface drainage, showing how a parsimonious parameterization of the physical system was sufficient for predicting the dynamics of subsurface drain flow rates. Gonçalvès et al. [2023] propose a conceptual model for the hydrogeological functioning of the Tindouf Aquifer, which spreads over Algeria, Morocco, Mauritania and Western Sahara (a region of lifelong interest for Ghislain de Marsily), building upon geomorphological, geological and hydrological remotely sensed and ground observations. Last, Schafmeister [2023] looks at aquifers from the radioactive waste repository point of view (which was also a topic of major interest for Ghislain de Marsily) and describes the current strategy in Germany, as well as the mistakes made in the seventies.

During the last decade, the issue of Water Security has been a topic of major interest for Ghislain de Marsily, and it is thus natural to see several related papers in this special issue: Billen and Garnier [2023] discuss the concept of water-agro-food system, first at the scale of the Seine basin, then enlarging it to the national, European and global scales. They couple it to the Riverstrahler model, in order to simultaneously address issues of food production, river water quality and nutrient delivery to the coastal zone. Meybeck et al. [2023] describe the work undertaken since 1989 in the framework of the interdisciplinary PIREN-Seine research program, combining historical river fluxes, material flows, river ecology, environmental history and political ecology. Last, Coudrain et al. [2023] discuss the Anthropocene concept, which tends to move science towards action, in order to actively promote solutions that adapt to changes.

Evaluation of hydrogeological models is a domain were Ghislain de Marsily had a remarkable contribution, being himself involved 30 years ago in the “impossible validation” controversy, which Andréassian [2023] revisits insisting on the necessity to look at the issue from two complementary points of view: model’s explanatory power (theoretical content) and the point of view of its predictive power.

Modelling the impact of climatic changes is the topic of several of the contributions of this special issue. Autin et al. [2023] use a distributed energy-balance model to reconstruct the maximum extent of a tropical glacier during the Little Ice Age in the late 17th century, using physically coherent climate scenarios constrained by information taken from paleoclimate proxies and sensitivity studies of past glacier advances. Their results highlight the importance of the seasonal pattern of precipitation to permit the existence of these glaciers.

An analysis of the complex interaction of water quality and climatic changes is proposed by Gascuel-Odoux et al. [2023], who propose a retrospective analysis based on data from European observatories. They argue for the need of a coupled approach because water quality integrates current and past (legacy) conditions, flow pathways, and biogeochemical reactivity. Besbes and Chahed [2023] discuss the predictability of water resources (blue and green water) made directly with Global Climate Models (GCMs), in the case of Northern Tunisia. The authors argue that the use of the raw GCMs predictions on large basins is possible with precisions comparable to what can be obtained with Regional Climate Models in medium size basins.

Runoff and the specificities of its generation in Sahelian landscapes is addressed by two papers dealing with the possible impact of climate change in Burkina Faso: Yonaba et al. [2023] use the Soil and Water Assessment Tool (SWAT) model to evaluate possible future changes in surface runoff in the Tougou catchment, paying special attention to the possible interactions between future climate changes and land use changes. Tirogo et al. [2023] focus on the impacts of climate change and pumping on groundwater in the Kou catchment: they show that the observed decrease in groundwater levels is due to the combined effect of precipitation deficits and increased pumping.

Submarine springs and karsts are discussed by Fleury et al. [2023], who analyze issues for the conservation of the water resources in coastal karst aquifers: they show that the possibility of natural seawater intrusion makes these aquifers particularly fragile, with the combined effect of the increase of sea level, that of more frequent and severe droughts, and that of an increase in withdrawals from aquifers for urban development. Sanz et al. [2023] analyze the controversy on the possible salinization mechanisms for coastal brackish springs (which present the puzzling characteristic to be able to discharge high flow rates with significant salinities at elevations of several meters above sea level). They show that spring salinity is mostly controlled by the weight of the water column flowing towards the spring mouth (for low flow rates) and by energy dissipation (for high flow rates). Labat et al. [2023] analyse a long-discharge time series available at an hourly time step for the Baget karstic spring (French Pyrenees). The analyses confirm the multiscale nature and the non-stationarity of the hydrological response. Last, Vasseur [2023] present a geothermal analysis of the Lez karstic spring (located near Montpellier, France): temperature measurements made above and below the underground karst network allow building a model to estimate the amount of geothermal energy captured by the flow system.

In the field of Geostatistics, four contributions are presented: first, Noetinger [2023] presents a study dealing with the upscaling of random fields, for improving quantitative hydrogeological predictions. He discusses how upscaling techniques allow lowering the dimension of the parameter space and, in the stochastic case, reduce the interaction between the conductivity spatial distribution and the flow pattern. Chihi et al. [2023] present a geostatistical analysis of a multiscale groundwater reservoir system, combining geological–geophysical investigations, geostatistics, and 3D geological modelling in the Jeffara basin of southeast Tunisia. The behaviour of a complex heterogeneous lacustrine carbonate formation in Argentina is modelled by Teles et al. [2023], using a bivariate plurigaussian geostatistical method to constrain the porosity simulation. Last, de Fouquet and Nos [2023] discuss the cokriging of transmissivity using head measurements and show that the estimation is improved in comparison with the case of head data from a single flow.

Little would have been achieved without a deep understanding of geology: First, Ledoux et al. [2023] examine chemical osmosis mechanisms and their impact on a collapsed salt cavity: the goal is to understand the mechanisms likely to generate salt fluxes towards surrounding aquifers and to allow the establishment of brine and dissolved salt balance. Davy et al. [2023] focus on fractured rock aquifers and propose three scale-independent indicators describing the fundamental characteristics of the flow/permeability relationship.

Yearning for the end of this already-too-long editorial, it seems natural to allocate these last lines to thank all the participants of this special issue for their enthusiasm, as well as the editorial team of the *Compte Rendus Géosciences*, who helped us achieve what we believe is a well-deserved tribute to our great colleague, friend, researcher and teacher, who has had a lasting impact on Geosciences over at least half a century.

Conflicts of interest

Authors have no conflict of interest to declare.

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Appendix

This appendix lists (in alphabetic order) the original works of Ghislain de Marsily which were cited by the papers in this special issue. This list is obviously not an exhaustive one, and is only aimed at providing a rapidly accessible account of Ghislain de Marsily's scientific production.

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