  Hydrology Research | 46.2 | 2015

Editorial: Hydrogeomorphology – a long-term scientific interface

Christophe Cudennec and Alban de Lavenne

ABSTRACT

Hydrogeomorphology is reframed as an old inter-discipline, which is still highly relevant to both hydrology and geomorphology, renewed by new techniques and new questions in line with challenges of ungauged basins; anthropogenic changes in driving forces, landscape structures, and dynamic functions; translation of science into practice; and retrospective and prospective analyses. The corpus and experience of hydrogeomorphology are also highlighted regarding new emerging sub- or inter-disciplines, in terms of epistemic bridging and dealing with complexity.

Key words | change, coevolution, inter-discipline, organized complexity, structure–function

Christophe Cudennec (corresponding author)
Alban de Lavenne
AGROCAMPUS OUEST, UMR 1069,
Soil Agrohydrosystems Spatialisation,
F-35000 Rennes, France;
INRA, UMR 1069, Soil Agrohydrosystems
Spatialisation, F-35000 Rennes, France;
and
Université Européenne de Bretagne, France
E-mail: *cudennec@agrocampus-ouest.fr*

Hydrological and water management issues are more and more related with connex compartments, structures, processes, dynamics, and hazards. Such connections and interfaces obviously follow the water flows between 'spheres': atmosphere, cryosphere, terrestrial/marine hydrospheres, and biosphere. Some others emerge in terms of nature–society interactions, through both water uses and land uses, and do not always display explicit, causal, and upstream–downstream relationships.

These issues are actually exacerbated by the question of changes, from global to local ones, and from external driving ones to internal ones within hydrosystems (Rockström & Karlberg 2010; Koutsoyiannis 2013; Montanari *et al.* 2013; Jimenez Cisneros *et al.* 2014; Savenije *et al.* 2014); with strong flow forward, feedforward, threshold, and tipping points effects. The hydrological complexity is thus more and more identified and tackled, but still not fully understood.

The scientific study of these connections and interfaces is classically based on the coupling of respective approaches, with strong challenges of making disciplinary semantics, variables, models, and other concepts converge. This is especially the case with soil–plant–atmosphere, surface–ground waters, and land–sea interactions (Hallett *et al.* 2010; Krause *et al.* 2011; Ubertini & Miralles-Wilhelm 2013; Cudennec *et al.* 2014). Some recent focuses on the water-food-energy nexus and on water security (UNEP 2009; Turral *et al.* 2011; UNESCO 2012; UN Water 2013; Cudennec *et al.* 2015) do reinforce such coupling challenges, with scientific questions arising from increasing practical and societal interconnected problems.

Beyond these coupling approaches, new systemic visions are emerging in order to bridge over these interfaces toward more integrated approaches. Some dedicated water-related focuses of wider disciplines are becoming explicit fields, such as hydroinformatics (Abbott 1999), hydropolitics, hydrodiplomacy, and hydropsychology (Sivakumar 2011, 2014; Asah 2015; Eliason 2015). Some converging (sub)disciplines are now being identified such as hydrometeorology and hydroclimatology (Peck 1978; Bengtsson 2013; Wilson *et al.* 2013), hydropedology (Lin 2003), biohydrology (Hallett *et al.* 2010), ecohydrology (Smettem 2008; Porporato & Rodriguez-Iturbe 2013), and ecohydraulics (Blanckaert *et al.* 2013) for a more comprehensive naturalism. And actually some holistic frames to address the nature–society interactions are being proposed, especially socio-hydrology (Sivapalan *et al.* 2012), renovated hydrological engineering (Koutsoyiannis 2014; Snelder *et al.* 2014) and knowledge dissemination (Koutsoyiannis & Kundzewicz 2007; Cudennec & Hubert 2008; Blöschl *et al.* 2014; Hughes *et al.* 2014).

Similarly to hydrogeology, hydrogeomorphology is an old inter-discipline whose history goes back to the late 1800s and has provided seminal papers with strong relevance for both hydrology and geomorphology (see Kirkby (2011) and Wohl (2014) for epistemic retrospectives), which

doi: 10.2166/nh.2015.100

remains explicitly actual and active (Sidle & Onda 2004), and which is still very promising.

Many aspects make hydrogeomorphology very rich in itself, several of them being addressed in this issue. Indeed, it is an inter-discipline studying complex interfaces, which refer to structure–function relationships, coevolutions, and multi-scale coupling and nesting. It is also a science, which faces strong challenges of identifying genericity and generalizing knowledge from a wide variability of specific settings.

The latter is obviously made necessary by the large hydro-geomorpho-climatic variability of the world, which requests comparisons, typologies, similarity approaches (Chalov & Alexeevsky 2015; Fraedrich 2015; Rajendra Prasad *et al.* 2015), then synoptic views (Cudennec *et al.* 2007), and ultimately syntheses toward improved understanding and predictions in data-scarce or -heterogeneous contexts (Blöschl *et al.* 2013; de Lavenne *et al.* 2015; Hannaford *et al.* 2013; Hrachowitz *et al.* 2013).

It is also made necessary by the avenue to explore and increasingly understand structure–function relationships to: (i) better value geographic observable features in the assessment of functional processes (Chalov & Alexeevsky 2015; de Lavenne *et al.* 2015; Tananaev 2015); (ii) hierarchize and better understand strong feedbacks from functional processes on geographic structural features – often at longer cumulative time scales or through intense and rare events – (Fraedrich 2015; Steudel *et al.* 2015); and (iii) assess the relative influence of anthropogenic drivers and artifacts, compared to natural ones, in actual hydrogeomorphology (Sivapalan *et al.* 2012; Montanari *et al.* 2013; Bao *et al.* 2015; Rapinel *et al.* 2015; Steudel *et al.* 2015). Further, many extraterrestrial studies do deduce functional planetary histories from morphological observations and extrapolation or analogy of the Earth hydrogeomorphology (Baker 2006; Burr *et al.* 2013).

It is of utmost interest in order to better assess the way how natural and anthropogenic compartments (such as land units as erosion sources – Rosen & Xu 2015; Rajendra Prasad *et al.* 2015; Tananaev 2015; terraced hillslopes or lacustrine banks – Steudel *et al.* 2015; Bao *et al.* 2015; or rivers and lakes as functional geometries – Chalov & Alexeevsky 2015, Fraedrich 2015; Rapinel *et al.* 2015) are articulated in parallel, sequence and cascade, through complex interfaces, scaling nets, anisotropies and convergences, and hysteresis effects, to better understand and quantify the overall picture and dominant dynamics which emerge from the hydrogeomorphological organized complexity (Blöschl & Sivapalan 1995; Rodriguez-Iturbe & Rinaldo 1997; Cudennec *et al.* 2004; Blöschl *et al.* 2013; Porporato & Rodriguez-Iturbe 2013; Singh *et al.* 2014).

Finally, this genericity seeking of the hydrogeomorphological inter-science from the worldwide hydro-geomorpho-climatic variability, of the structure–function relationships, and of emerging dynamics from the complexity of organized compartments has now to be put in an explicit temporal perspective. This perspective is multiple. The long-term perspective is needed to address the corresponding processes and structural evolutions. Long-term retrospectives are needed in this regard, including palaeo-studies (MacDonald & Herget 2013; Szafraniec 2013; Baker 2014), to understand hydrogeomorphological trajectories, to assess the influence of extreme events, and to decipher the influences of natural and anthropogenic drivers. The shorter-term analyses, from the event to the interannual scales, either in chronological, frequency, or spectral dimensions, are also needed to understand the corresponding dynamics, contingencies, non-linearities, and hazards, and to identify changes from variability. This strengthens approaches to explore and predict prospective dynamics, either through more explicit and geomorphology-based scenarios or through more comprehensive interdisciplinary approaches. Such explicit hydrogeomorphological approaches are very promising in order to reinforce the socio-hydrological understanding and stewardship of actual changes (Sivapalan *et al.* 2012; Koutsoyiannis 2013; Montanari *et al.* 2013; Jimenez *et al.* 2014; Savenije *et al.* 2014) as many ecological and human geographic dynamics are actually driven by relations to water and/or geomorphology (Porporato & Rodriguez-Iturbe 2013; Savenije *et al.* 2014; Manfreda *et al.* 2014; Viglione *et al.* 2014). This is now widely acknowledged, all the more thanks to new high-resolution observation techniques (Tarolli 2014; Rapinel *et al.* 2015), from local controls on elementary hydrogeomorphological compartments (Wohl 2014) such as hillslope terracing and best management practices (Nasri *et al.* 2004; Chen *et al.* 2014; Steudel *et al.* 2015), wetland conservation and engineering (Krause *et al.* 2011; Blanckaert *et al.* 2013; Rapinel *et al.*

2015), or (peri-)urban green design, to huge dams and water-related infrastructures setting up and management (Bao *et al.* 2015). And it leads to strongly tangible emerging hydrogeomorphological effects at upper levels, up to the continental and global ones, in the frame of the Anthropocene (Meybeck 2003; Rockström & Karlberg 2010; Steffen *et al.* 2011; Syvitski & Kettner 2011; Wilson *et al.* 2013). Yet, it conversely opens new (blue-)green integrated approaches to increase territorial resilience toward stronger water security.

Hydrogeomorphology is thus a long-term scientific interface as an old inter-discipline, which on the one hand deals with multi-temporal scale dynamics, trajectories, and changes; and on the other hand offers a strong background for long-term retrospective and prospective analyses. The corresponding strong interdisciplinary corpus and experience are also highly valuable to many emerging environmental inter-disciplines to address the related bridging epistemic challenges. The importance of hydrogeomorphological objects, dynamics, heritages, and perceptions – which universally underlie many human and ecosystemic land- and water-related dynamics and rationales – finally puts hydrogeomorphological science in a strong interface with societal challenges.

REFERENCES

Abbott, M. B. 1999 Introducing hydroinformatics. *Journal of Hydroinformatics* **1**, 3–19.

Asah, S. T. 2015 Transboundary hydro-politics and climate change rhetoric: an emerging hydro-security complex in the lake chad basin. *WIREs Water* **2**, 37–45.

Baker, V. R. (ed.) 2014 *Palaeohydrology*. Benchmark Papers in Hydrology, 9, IAHS Press, Wallingford, UK.

Baker, V. R. 2006 Geomorphological evidence for water on Mars. *Elements* **2**, 139–143.

Bengtsson, L. 2013 Hydroclimatological processes in northern river basins. *Hydrology Research* **44**, 1–1.

Blanckaert, K., Garcia, X. -F., Steiger, J. & Uijttewaal, W. 2013 Ecohydraulics: linkages between hydraulics, morphodynamics and ecological processes in rivers. *Ecohydrology* **6**, 507–510.

Bao, Y., Tang, Q., He, X., Hu, Y. & Zhang, X. 2015 Soil erosion in the riparian zone of the Three Gorges Reservoir, China. *Hydrology Research* **46** (2), 212–221.

Blöschl, G. & Sivapalan, M. 1995 Scale issues in hydrological modelling: a review. *Hydrological Processes* **9**, 251–290.

Blöschl, G., Sivapalan, M., Wagener, T., Viglione, A. & Savenije, H. 2013 *Runoff Prediction in Ungauged Basins: Synthesis across Processes, Places and Scales*. Cambridge University Press, Cambridge, UK.

Blöschl, G., Bardossy, A., Koutsoyiannis, D., Kundzewicz, Z., Littlewood, I., Montanari, A. & Savenije, H. 2014 On the future of journal publications in hydrology. *Hydrology Research* **45**, 515–518.

Burr, D. M., Perron, J. T., Lamb, M. P., Irwin, R. P., Collins, G. C., Howard, A. D., Sklar, L. S., Moore, J. M., Adamkovics, M., Baker, V. R., Drummond, S. A. & Black, B. A. 2013 Fluvial features on Titan: insights from morphology and modeling. *Geological Society of America Bulletin* **125**, 299–321.

Chalov, S. R. & Alexeevsky, N. I. 2015 Braided rivers: structure, types and hydrological effects. *Hydrology Research* **46** (2), 258–275.

Cudennec, C. & Hubert, P. 2008 The multi-objective role of HSJ in processing and disseminating hydrological knowledge. *Hydrological Sciences Journal* **53**, 485–487.

Cudennec, C., Fouad, Y., Gatot, I. S. & Duchesne, J. 2004 A geomorphological explanation of the unit hydrograph concept. *Hydrological Processes* **18**, 603–621.

Cudennec, C., Leduc, C. & Koutsoyiannis, D. 2007 Dryland hydrology in Mediterranean regions – a review. *Hydrological Sciences Journal* **52**, 1077–1087.

Cudennec, C., Kravchishina, M., Lewandowski, J., Rosbjerg, D. & Woodworth, P. 2014 *Complex Interfaces under Change: Sea – River – Groundwater – Lake*. IAHS Publ. 365, IAHS Press, Wallingford, UK.

Cudennec, C., Demuth, S., Mishra, A. & Young, G. 2015 *Hydrological Sciences & Water Security: Past, Present, Future*. IAHS Publ. 366, IAHS Press, Wallingford, UK, in press.

Chen, S-K., Chen, R-S. & Yang, T-Y. 2014 Application of a tank model to assess the flood-control function of a terraced paddy field. *Hydrological Sciences Journal* **59**, 1020–1031.

de Lavenne, A., Boudhrâa, H. & Cudennec, C. 2015 Streamflow prediction in ungauged basins through geomorphology-based hydrograph transposition. *Hydrology Research* **46** (2), 291–302.

Eliason, J. 2015 The rising pressure of global water shortages. *Nature* **517**, 6.

Fraedrich, K. 2015 A minimalist model of terminal lakes: Qinghai Lake (China) and Lake Chad (N-Africa). *Hydrology Research* **46** (2), 222–231.

Hallett, P. D., Lichner, L. & Cerdà, A. 2010 Biohydrology: coupling biology and soil hydrology from pores to landscapes. *Ecohydrology* **3**, 379–381.

Hannaford, J., Holmes, M. G. R., Laizé, C. L. R., Marsh, T. J. & Young, A. R. 2013 Evaluating hydrometric networks for prediction in ungauged basins: a new methodology and its application to England and Wales. *Hydrology Research* **44**, 401–418.

Hrachowitz, M., Savenije, H. H. G., Blöschl, G., McDonnell, J. J., Sivapalan, M., Pomeroy, J. W., Arheimer, B., Blume, T., Clark, M. P., Ehret, U., Fenicia, F., Freer, J. E., Gelfan, A., Gupta, H. V., Hughes, D. A., Hut, R. W., Montanari, A., Pande, S., Tetzlaff, D., Troch, P. A., Uhlenbrook, S., Wagener, T., Winsemius, H. C., Woods, R. A., Zehe, E. & Cudennec, C. 2013 A decade of predictions in ungauged basins (PUB) – a review. *Hydrological Sciences Journal* **58**, 1198–1255.

Hughes, D. A., Heal, K. V. & Leduc, C. 2014 Improving the visibility of hydrological sciences from developing countries. *Hydrological Sciences Journal* **59**, 1627–1635.

Jiménez Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., Döll, P., Jiang, T. & Mwakalila, S. S. 2014 Freshwater resources. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea & L. L. White, eds). Cambridge University Press, Cambridge, UK, pp. 229–269.

Kirkby, M. J. (ed.) 2011 *Hydro-Geomorphology, Erosion and Sedimentation*. Benchmark Papers in Hydrology, 6, IAHS Press, Wallingford, UK.

Koutsoyiannis, D. 2013 Hydrology and change. *Hydrological Sciences Journal* **58**, 1177–1197.

Koutsoyiannis, D. 2014 Reconciling hydrology with engineering. *Hydrology Research* **45**, 2–22.

Koutsoyiannis, D. & Kundzewicz, Z. W. 2007 Editorial – quantifying the impact of hydrological studies. *Hydrological Sciences Journal* **52**, 3–17.

Krause, S., Hannah, D. M., Sadler, J. P. & Wood, P. J. 2011 Ecohydrology on the edge: interactions across the interfaces of wetland, riparian and groundwater-based ecosystems. *Ecohydrology* **4**, 477–480.

Lin, H. S. 2003 Hydropedology: bridging disciplines, scales and data. *Vadose Zone Journal* **2**, 1–11.

Macdonald, N. & Herget, J. 2013 Editorial: historical and palaeofloods in Earth's history. *Hydrology Research* **44**, 199–201.

Manfreda, S., Nardi, F., Samela, C., Grimaldi, S., Taramasso, A. C., Roth, G. & Sole, A. 2014 Investigation on the use of geomorphic approaches for the delineation of flood prone areas. *Journal of Hydrology* **517**, 863–876.

Meybeck, M. 2003 Global analysis of river systems: from Earth system controls to Anthropocene syndromes. *Philosophical Transactions of the Royal Society of London B* **358**, 1935–1955.

Montanari, A., Young, G., Savenije, H. H. G., Hughes, D., Wagener, T., Ren, L. L., Koutsoyiannis, D., Cudennec, C., Toth, E., Grimaldi, S., Blöschl, G., Sivapalan, M., Beven, K., Gupta, H., Hipsey, M., Schaefli, B., Arheimer, B., Boegh, E., Schymanski, S. J., Di Baldassarre, G., Yu, B., Hubert, P., Huang, Y., Schumann, A., Post, D., Srinivasan, V., Harman, C., Thompson, S., Rogger, M., Viglione, A., McMillan, H., Characklis, G., Pang, Z. & Belyaev, V. 2013 'Panta Rhei – everything flows': change in hydrology and society – the IAHS Scientific Decade 2013–2022. *Hydrological Sciences Journal* **58**, 1256–1275.

Nasri, S., Albergel, J., Cudennec, C. & Berndtsson, R. 2004 Hydrological processes in macrocatchment water harvesting in the arid region of Tunisia: the traditional system of tabias. *Hydrological Sciences Journal* **49**, 261–272.

Peck, E. L. 1978 Hydrometeorology. *Bulletin of the American Meteorological Society* **59**, 609–612.

Porporato, A. & Rodriguez-Iturbe, I. 2013 From random variability to ordered structures: a search for general synthesis in ecohydrology. *Ecohydrology* **6**, 333–342.

Rajendra Prasad, P., Reddy, N. L. K., Prasad, N. V. B. S. S. & Nooka Raju, D. 2015 Integrated water resources assessment and management in a small watershed – a geomorphic approach. *Hydrology Research* **46** (2), 180–191.

Rapinel, S., Hubert-Moy, L., Clément, B., Nabucet, J. & Cudennec, C. 2015 Ditches network extraction and hydrogeomorphological characterization using LiDAR-derived DTM in wetlands. *Hydrology Research* **46** (2), 276–290.

Rockström, J. & Karlberg, L. 2010 The quadruple squeeze: defining the safe operating space for freshwater use to achieve a triply green revolution in the Anthropocene. *Ambio* **39**, 257–265.

Rodriguez-Iturbe, I. & Rinaldo, A. 1997 *Fractal River Basins; Chance and Self-organization*. Cambridge University Press, Cambridge, UK.

Rosen, T. & Xu, Y. J. 2015 Estimation of sedimentation rates in the distributary basin of the Mississippi River, the Atchafalaya River Basin, USA. *Hydrology Research* **46** (2), 244–257.

Savenije, H. H. G., Hoekstra, A. Y. & van der Zaag, P. 2014 Evolving water science in the Anthropocene. *Hydrology Earth System Sciences* **18**, 319–322.

Sidle, R. C. & Onda, Y. 2004 Hydrogeomorphology: overview of an emerging science. *Hydrological Processes* **18**, 597–602.

Singh, P. K., Mishra, S. K. & Jain, M. K. 2014 A review of the synthetic unit hydrograph: from the empirical UH to advanced geomorphological methods. *Hydrological Sciences Journal* **59**, 239–261.

Sivakumar, B. 2011 Hydropsychology: the human side of water research. *Hydrological Sciences Journal* **56**, 719–732.

Sivakumar, B. 2014 Planning and management of shared waters: hydropolitics and hydropsychology – two sides of the same coin. *International Journal of Water Resources Development* **30**, 200–210.

Sivapalan, M., Savenije, H. H. G. & Blöschl, G. 2012 Socio-hydrology: a new science of people and water. *Hydrological Processes* **26**, 1270–1276.

Smettem, K. R. J. 2008 Welcome address for the new 'Ecohydrology' journal. *Ecohydrology* **1**, 1–2.

Snelder, T. H., Rouse, H. L., Franklin, P. A., Booker, D. J., Norton, N. & Diettrich, J. 2014 The role of science in setting water resource use limits: case studies from New Zealand. *Hydrological Sciences Journal* **59** (3–4), 844–859.

Steudel, T., Bugan, R., Kipka, H., Pfennig, B., Fink, M., de Clercq, W., Flügel, W-A. & Helmschrot, J. 2015 Implementing contour bank farming practices into the J2000 model to improve hydrological and erosion modeling in semi-arid

Western Cape Province of South Africa. *Hydrology Research* **46** (2), 192–211.

Steffen, W., Grinevald, J., Crutzen, P. & McNeill, J. 2011 The Anthropocene: conceptual and historical perspectives. *Philosophical Transactions of the Royal Society A* **369**, 842–867.

Syvitski, J. P. M. & Kettner, A. 2011 Sediment fluxes and the Anthropocene. *Philosophical Transactions of the Royal Society A* **369**, 957–975.

Szafraniec, J. E. 2013 Paleoflood marks in sandur morphometry as the result of the glacier surge (NW Poland). *Hydrology Research* **44**, 264–280.

Tananaev, N. I. 2015 Hysteresis effects of suspended sediment transport in relation to geomorphic conditions and dominant sediment sources in medium and large rivers of Russian Arctic. *Hydrology Research* **46** (2), 232–243.

Tarolli, P. 2014 High-resolution topography for understanding Earth surface processes: opportunities and challenges. *Geomorphology* **216**, 295–312.

Turral, H., Burke, J. & Faurès, J. M. 2011 *Climate Change, Water and Food Security*. FAO Water Reports, 36, FAO, Rome, Italy.

Ubertini, L. & Miralles-Wilhelm, F. 2013 New frontiers of hydrology: soil, water, and vegetation monitoring and modeling. *Irrigation and Drainage* **62** (2), 3–4.

UNEP 2009 *Water Security and Ecosystem Services – The Critical Connection*. UNEP, Nairobi, Kenya.

UNESCO 2012 *Water Security: Responses to Local, Regional and Global Challenges*. International Hydrological Programme (IHP) Eight Phase (2014–2021) Strategic Plan, UNESCO, Paris, France.

UN Water 2013 *Water Security & the Global Water Agenda*. UN Water Analytical Brief, United Nations University, Hamilton, Canada.

Viglione, A., Di Baldassarre, G., Brandimarte, L., Kuil, L., Carr, G., Salinas, J. L., Scolobig, A. & Blöschl, G. 2014 Insights from socio-hydrology modeling on dealing with flood risk – roles of collective memory, risk-taking attitude and trust. *Journal of Hydrology* **518**, 71–82.

Wilson, D., Hannah, D. M. & McGregor, G. R. 2013 A large-scale hydroclimatological perspective on western European river flow regimes. *Hydrology Research* **44**, 809–833.

Wohl, E. 2014 Time and the rivers flowing: fluvial geomorphology since 1960. *Geomorphology* **216**, 263–282.