Ecohydrology—seeking consensus on interpretation of the notion

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Abstract There has been no ubiquitously and unanimously accepted definition of the term ecohydrology (hydro-ecology). The present contribution aims to stir discussion, which may lead to getting closer to a consensus on the interpretation of the notion. A robust finding, holding across a range of existing definitions, is that the dynamically developing area of ecohydrology holds potential to be a very important tool serving sustainable development and management of water resources.

Key words ecohydrology; hydro-ecology; sustainable development; water resources

Ecohydrologie—à la recherche d'un consensus sur l'interprétation de la notion

Résumé Il n'existe pas de définition ubiquiste et unanime du terme écohydrologie (hydro-écologie). Cette contribution a pour but de stimuler un débat, afin de tendre vers un consensus sur l'interprétation de cette notion. Il apparaît fermement, à travers un ensemble de définitions existantes, que le domaine en plein développement de l'écohydrologie peut devenir un outil très important au service du développement durable et de la gestion des ressources en eau.

Mots clefs écohydrologie; hydro-écologie; développement durable; ressources en eau

INTRODUCTION

Hydrological sciences have developed a wealth of knowledge for providing answers to many problems of interest and importance to other disciplines. Yet, the interactions between hydrological systems and other interlinked (e.g. geophysical, biological, and socio-economic) systems have been limited to date, leading to discontinuities and problems in communication between disciplines. It is now being increasingly understood that complex scientific questions and environmental problems can be effectively tackled only if disciplines are considered jointly. This new paradigm of interactive hydrology necessitates interest in, and care of, the interfaces between hydrology and other disciplines. This new territory has been populated by a number of new disciplines and ecohydrology is one of the most, if not the most, vigorous of them.

Consistent with etymological interpretation, ecohydrology (or hydro-ecology) links ecology (the science of the interrelationships between living organisms and their environment) and hydrology (the science of the hydrological cycle, dealing with the properties, distribution, and circulation of water in the environment).

Open for discussion until 1 April 2003

ECOHYDROLOGY AND HYDRO-ECOLOGY—NOTIONS AND INTERPRETATIONS

Many scientists follow the Zalewski *et al.* (1997) concept of the integration of ecology and hydrology backing the ecohydrology paradigm. Zalewski's reminder of a Platonian superorganism, consisting of a catchment (geosphere), water (hydrosphere) and biota (biosphere), fits well to the holistic perspective, which has been gaining broader recognition in the hydrological sciences. There, the concept of integrative hydrology also contains further important components, related to socio-economics: anthroposphere, sociosphere, technosphere, econosphere, etc. Zalewski *et al.* (1997) believe that ecohydrology can serve reduction of threats and amplification of chances and can contribute to alleviation of all three types of water problems—having too much, too little, and too polluted water.

The emerging discipline of ecohydrology has been also tackled independently by other, somewhat isolated, groups of scientists, with little communication between them. Different definitions have thus been devised. Indeed, the term "ecohydrology" is not a registered trademark. In general, lack of crisp delineation of the borders of any new research area, or emerging discipline, is not unexpected in its infancy phase. Ecohydrology (or hydro-ecology) is indeed *in statu nascendi*, offering many scientific challenges and much room for excitement and dynamic development. Possibly more time is needed before the notion ripens and a broader consensus on the interpretation of the term emerges?

The scientific groups active in the area, which they call ecohydrology (or hydro-ecology), are already well advanced. The achievements of the UNESCO International Hydrological Programme (IHP), IHP-V projects 2.3/2.4 led by Maciej Zalewski have led to a number of milestone publications, such as Zalewski *et al.* (1997), a special issue of *Ecological Engineering* journal, devoted entirely to ecohydrology and guest-edited by Zalewski (2000) and emergence of a new journal dedicated to ecohydrology. Also, other, independent groups of experts dealing with the area have made important contributions, including two recent books having ecohydrology or hydro-ecology in the title (Baird & Wilby, 1999; Acreman, 2001), in addition to numerous journal papers, reports and contributions to conferences.

As expected, definitions thus far of ecohydrology and hydro-ecology refer to some sort of integration of the two disciplines: ecology and hydrology. One perception of the compound discipline is an overlap (logical product) between the two, while the alternative perception focuses on impacts of one on another (impact of hydrological systems on ecological systems and/or *vice versa*).

It could be instructive to review a sample of definitions developed independently of the UNESCO IHP. Several early uses of the notion were restricted to "wet" ecosystems—wetlands, marshes, peatlands, and aquatic ecosystems, e.g. Ingram (1987), reporting on the ecohydrology of peatlands.

It is not widely known that a germane notion of "ecohydraulics" was coined in the mid 1970s in Japan. Hino (1977) proposed this term to denote an ensemble of such topics as: influence of aquatic plants on flow conditions, hydraulic view of photo-synthesis, self-purification in streams, and diffusion of radioactive waste and bio-accumulation. He called upon hydraulic sciences to go beyond the classical realm of pure hydraulics and to delve into the interface with ecology. While it is unclear who may have used the term "ecohydrology" for the first time, the informal use of this term seems to have started decades ago; perhaps following Hino's idea of ecohydraulics, or perhaps following a general fashion to combine the prefix "eco-" with other terms.

Vigorous activities in areas labelled as ecohydrology and hydro-ecology took place in The Netherlands in the late 1980s and early 1990s, among academia, administrators, and practitioners. In 1991, the Dutch Association for Landscape Ecology (WLO) organized a meeting on "Hydro-ecological prediction methods for policy and management" with several follow-up activities, such as a roster of further meetings and publications (cf. Hooghart & Posthumus, 1993). One of the central issues inherent in the notion was the Dutch term "*verdroging*", i.e. the "ecological decline of nature reserves and natural elements in the agricultural landscape". Among the many Dutch contributions to this topical area, Pedroli (1990) reported on ecohydrological parameters indicating different types of shallow groundwater. Garritsen (1993) distinguished between ecohydrological and hydro-ecological modelling; the former comprising "primarily hydrological modelling to supply data for ecological modelling", and the latter linking "the abiotic characteristics of the site to vegetation". Wassen & Grootjans (1996) opened a special issue of the journal *Vegetatio*, devoted to ecohydrology, with a paper entitled "Ecohydrology: an interdisciplinary approach for wetland management and restoration". They described the topical area of ecohydrology by referring to hydrological factors determining the natural development of wet ecosystems, especially in regard of their functional value for river protection and restoration.

However, as stated by Baird & Wilby (1999): "[al]though the term 'ecohydrology' has been frequently coined by ecologists to describe interactions between water tables and plant distributions in wetlands, it can be used to describe plant–water interactions in other environments." In the book on ecohydrology edited by Baird & Wilby (1999), the authors dealt with plant–water interactions in a variety of terrestrial and aquatic environments, including drylands, freshwater wetlands, forests and woodlands, streams, rivers, lakes and their neighbourhoods. Yet, even if Baird & Wilby (1999) rightly see their definition as a generalization of the earlier narrow notion of wet-environment plant–water links, other scientists feel that their broader definition is still not general enough, being restricted to flora, while fauna—an important component of ecosystems—are not included.

In a recent paper, colloquially termed by some scientists as an "ecohydrology manifesto", Rodriguez-Iturbe (2000), defined ecohydrology as the science, which seeks to describe the hydrological mechanisms that underlie ecological patterns and processes. He concentrated on those processes in which soil moisture is the key link between climate fluctuations and vegetation dynamics in space and time. The climate–soil–vegetation dynamics, as discussed in Eagleson (1978) and several further contributions, is seen as the core of hydrology itself. Rodriguez-Iturbe (2000) argued that ecohydrology should have (but does not yet have) a central role in hydrological research, and that major breakthroughs and intensive activity are expected in the present decade. He believed that "the spatiotemporal linkage" between the hydrological and ecological dynamics could be one of the most exciting frontiers of the future: "It is full of challenging and unexplored questions which go to the heart of hydrology and which are of fundamental importance for understanding the environment in which we live and the state in which it will be inherited by future generations."

Apart from the notion of ecohydrology, there are several uses of a term "hydro-ecology" and this may render the layman even more confused. As put by Baird & Wilby (1999), this term is being "used in a narrower sense to describe the study of ecological and hydrological processes in rivers and floodplains". In a book on hydro-ecology, edited by Acreman (2001), a definition of applied hydro-ecology was proposed as "the linkage of knowledge from hydrological, hydraulic, geomorphological and biological/ecological sciences to predict the response of freshwater biota and ecosystems to variation of abiotic factors over a range of spatial and temporal scales" (Dunbar & Acreman, 2001). This interpretation includes the study of changes in aquatic ecosystems resulting from alterations to a river's flow regime, channel structure, and water quality.

There is quite a confusion, not only as to the difference between the competing definitions of the term "ecohydrology", but also as to those between this term and "hydro-ecology". Following the rules of the English language, one can interpret the prefix "eco-" in the term "ecohydrology" as a modifier of the basic word "hydrology", i.e. the notion being more about hydrology than ecology (or perhaps dealing with impacts of ecology on hydrology). Similarly, "hydro-" in the term "hydro-ecology" can be interpreted as a modifier of the basic word "ecology" and one could understand that this notion is more about ecology than hydrology, (representing the impacts of hydrology on ecology?). Yet, this logic does not necessarily hold in other compound names of scientific disciplines, which are not "fully convertible". For instance, there exist such terms as "biophysics" and "biochemistry" but not "physicobiology" or "chemobiology" (in fact, these latter names would sound or look somewhat odd). On the other hand, the fashionable prefix "eco-" has often been used in colloquial connotations, with loose, if any, link to the scientific discipline of ecology. Such a prefix often means: "related to environment" ("enviro-" would have been longer and less appealing), environment-friendly, benefiting the environment, e.g. by conservation of energy, water, raw materials, and not exceedingly loading the environment by waste or pollution.

It is instructive to look at relationships between the two interlinked (or partially overlapping) disciplines: ecology and hydrology. If one interprets ecohydrology (or hydro-ecology) as a common part (logical product) of ecology and hydrology, it is still not quite clear how far to go in the inclusion of relevant issues. One can claim that there are several hydrological issues, which do not have much in common with ecology, but even these issues do impact life and ecosystems, and *vice versa*. It is indeed difficult to identify a sub-area of hydrology, which does not impact the biosphere (at least indirectly) and is not impacted by the biosphere.

Therefore, depending on the approach, the notion of ecohydrology may include such topical areas as: aquatic habitat (depending on flow, water level, temperature, chemical composition, etc.), eutrophication, algae growth, plant growth in surface water including water weeds, hydraulic roughness, wetlands, biohydrochemical barriers (e.g. trapping nutrient-rich drainage from agricultural fields, or eroded phosphorus-loaded soil), ecotones, riparian vegetation, buffering capacity, etc. Plants do actively participate in the hydrological cycle and many of water fluxes, such as transpiration and evapotranspiration, interception, stemflow, throughfall, sediment transport, soil water depletion, water intake, plant water use, and also water quality, have explicit links with vegetation. On the other hand, water-related stresses in plants are caused by extreme hydrological events—droughts and floods.

Interactive hydrology, in particular at the hydrology–ecology frontier, is high on the recent agenda of research, including high profile international endeavours, such as HELP (Hydrology for Environment, Life and Policy) of the UNESCO IHP; BAHC (Biospheric Aspects of Hydrological Cycle) of the IGBP (International Geosphere–Biosphere Programme); ICASVR (the International Commission on Atmosphere–Soil–Vegetation Relationships) of IAHS; and SWAT (soil–water–atmosphere transfer) activities. The ecohydrological components play a pivotal role in such high-profile global issues as climate change, biodiversity, desertification, all being subjects of international conventions.

Studies linking hydrology and ecology, e.g. of connections between the freshwater biota and physical water characteristics, have been reported since several decades (e.g. Baxter, 1961), before the names ecohydrology and hydro-ecology were coined. In the spirit of ecohydrology (yet, without the use of the term) were the seminal, and milestone publications by Eagleson (1978) on water, climate, soil, and vegetation relationships (and also on the balance between vegetation and the environment, water-related ecological optimality and the role of particular types of vegetation around the globe), and by Naiman *et al.* (1995) on the freshwater initiative—inland water ecology/freshwater ecology.

Some scientists have used the term "ecohydrology" to denote different topical issues, at different scales of generalization; many others have dealt with the essence of the notion, not using the term "ecohydrology" itself.

CONCLUSIONS

Having defined ecohydrology, Zalewski *et al.* (1997) envisaged it as a tool of considerable potential use for sustainable development and management of water resources (cf. Kundzewicz, 2002).

This seems to be a robust finding, which holds across a range of definitions and interpretations of ecohydrology and across a range of notions, criteria and indices of sustainable development (Kundzewicz, 2001, 2002). Ecohydrology alone will not eliminate threats, but can largely contribute to their alleviation, together with other means, such as improving awareness, participation, legislation, empowerment, organization, institutions, etc. Water is not a free good any more. A future-oriented water resources management programme should emphasize shaping demands rather than supply extension. It is a must to improve the efficiency of water use, trying to "do more with less" (Kundzewicz, 2000), e.g. trying to double the output while halving the resource use, thereby achieving (even if not very cheaply) a "factor four" improvement (von Weizsäcker *et al.*, 1997). Financial instruments, such as water pricing, not only granting full cost recovery but also accounting the cost of the resource in the sense of foregone opportunities, are another means to improve efficiency of water use. Thus, ecohydrology can be seen as a very important element of "interactive hydrology", whose development and practical application are of primary importance to sustain the humans in harmony with the environment.

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REFERENCES:

Acreman, M. C. (ed.) (2001) *Hydro-ecology: Linking Hydrology and Aquatic Ecology* (Proc. Birmingham Workshop, July 1999), IAHS Publ. no. 266.

Baird, A. J. & Wilby, R. L. (eds) (1999) *Ecohydrology. Plants and Water in Terrestrial and Aquatic Environments*, Routledge, London, UK.

Baxter, G. (1961) River utilisation and the preservation of migratory fish life. *Proc. Instn Civil Engrs* **18**, 225–244.

Dunbar, M. J. & Acreman, M. C. (2001) Applied hydro-ecological science for the twenty-first century. In: *Hydro-ecology: Linking Hydrology and Aquatic Ecology* (Proc. Birmingham Workshop, July 1999) (ed. by M. C. Acreman), 3–20. IAHS Publ. no. 266.

Eagleson, P. S. (1978) Climate, soil, and vegetation (parts 1–7). *Wat. Resour. Res.* **14**, 705–776.

Garritsen, A. C. (1993) Linking hydrological and ecological models. In: *The Use of Hydro-ecological Models in the Netherlands* (ed. by J. C. Hooghart & C. W. S. Posthumus), 67–79. Proceedings and Information no. 47, TNO Committee on Hydrological Research, Delft, The Netherlands.

Hino, M. (1977) Eco-hydraulics, an attempt. Tech. Report no. 22, Department of Civil Engineering, Tokyo Institute of Hydrology, 29–59. (also presented at the XVIIth Congress of the International Association for Hydraulic Research, held in Baden-Baden in August 1977).

Hooghart, J. C. & Posthumus, C. W. S. (eds) (1993) *The Use of Hydro-ecological Models in the Netherlands*. Proceedings and Information no. 47, TNO Committee on Hydrological Research, Delft, The Netherlands.

Ingram, H. A. P. (1987) Ecohydrology of Scottish peatlands. *Trans. Roy. Soc. Edinburgh: Earth Sciences* **78**, 287–296.

Kundzewicz, Z. W. (2000) *Gdyby mała wody miarka. Zasoby wodne dla trwałego rozwoju*, (If a small water measure... Water resources for sustainable development, in Polish). Wydawnictwo Naukowe PAN, Warsaw, Poland.

Kundzewicz, Z. W. (2001) Some for all, forever—sustainable development and management of water resources. *Int. J. Sustain. Dev. World Ecol.* **8**, 290–298.

Kundzewicz, Z. W. (2002) Ecohydrology for sustainable development and management of water resources. *Int. J. Ecohydrol. and Hydrobiol.* (in press.).

Naiman, R. J., Magnuson, J. J., McKnight, D. M. & Stanford, J. A. (eds) (1995) *The Freshwater Imperative: A Research Agenda*. Inland Press, Washington, D C, USA.

Pedroli, G. B. M. (1990) Ecohydrological parameters indicating different types of shallow groundwater. *J. Hydrol.* **120**, 381–404.

Rodriguez-Iturbe, I. (2000) Ecohydrology: a hydrologic perspective of climate–soil–vegetation dynamics. *Wat. Resour. Res.* **36**(1), 3–9.

Von Weizsäcker, E., Lovins, A. B. & Lovins, L. H. (1997) *Factor Four: Doubling Wealth—Halving Resource Use. The New Report to the Club of Rome.* Earthscan, London, UK.

Wassen, M. J. & Grootjans, A. P. (1996) Ecohydrology: an interdisciplinary approach for wetland management and restoration. *Vegetatio* **126**, 1–4.

Zalewski, M. (ed.) (2000) Ecohydrology. *Ecol. Engng* Special Issue **16**, 1–197.

Zalewski, M., Janauer, G. A. & Jolankai, G. (1997) *Ecohydrology. a new paradigm for the sustainable use of aquatic resources.* IHP-V. Tech. Documents in Hydrology no. 7. UNESCO, Paris, France.