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Ecohydrology: fusing concepts and scales

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Abstract

'Hydrology and Water Resources Development in a Vulnerable Environment' is the topic of the current phase of IHP-V. To ascertain sustainable use of landscape resources, ecohydrological processes in the surficial environment must be studied. The objectives of Project 2.3 are the interactions between river systems, floodplains, and wetlands. The gap between hydrology and ecology must be closed to understand the hydrological cycle in different ecosystems and to gain more detailed information on the plant and animal communities that influence the flow of water and its contents. Project 2.4 aims at the comprehensive assessment of the surficial ecohydrological processes on a global scale. Through experimental research, flow of water, sediments, nutrients, and pollutants in different scales, climates and geographic regions must be studied. Non-structural measures for construction and management should be evaluated with respect to environmental quality enhancement, and water ecosystem vulnerability should be assessed. It is the incitement to collect hydrological and ecological data in a more balanced way. Efficient lines of research in ecohydrology start with getting to know the partner's concepts and to begin to think in the partner's scales. This will indicate the start of genuine integrated research with all partners joined in an interdisciplinary network.

Keywords: Ecohydrology; International Hydrological Program; Environment; Water resources; Sustainable development

1. Introduction

The current phase of the International Hydrological Programme (IHP-V) has made "Hydrology and Water Resources Development in a Vulnerable Environment" its main topic. The development of water resources to the benefit of humans will cause impacts on the environment that must be counteracted to prevent permanent negative effects, if sustainable use of landscape resources is envisaged. Theme 2 of IHP-V focuses on ecohydrological processes in the surficial environment: it is the incitement to study the interdependence of hydrology and ecology, to apply humanity's power to change the water's course to the benefit of all living things in this world.

1.1. IHP-V

UNESCO's current International Hydrological Programme, fifth phase (IHP-V), deals with different aspects of hydrology and water resources development. Two chapters, Projects 2.3/2.4, are specially devoted to the ecological aspects of the environment.

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Project 2.3, (UNESCO (1996), p. 19) focuses research on the interactions between river systems, floodplains, and wetlands. This focus is important to theoretical and practical hydrology, and ecology as well as understanding the hydrological cycle in different ecosystems and the links between abiotic and biotic parameters is indicative for maintaining the filtering capacity of flood plains and wetlands, with respect to sediments, nutrients, pollutants, and the buffering of extreme hydrological events. The gap between hydrology and ecology may be closed by more sophisticated numerical information on biotic structural elements like ecotones and vegetation patches, which influence the flow of water and its contents as well as the faunistic aspect of landscape units.

Table 1
Working hypotheses on ecohydrology (Zalewski et al., 1997)

1. To achieve profound understanding for the present hydrological regime and distribution of biota in fluvial corridors, historical changes should be analysed, and interpreted for application
2. The ecohydrological approach can be a tool towards the sustainable use of aquatic resources by enhancement of the resistance, resilience, and buffering capacity of fluvial corridors
3. Vulnerability of rivers, reservoirs, and estuaries is dependent on the seasonal pattern of hydrological and biotic processes and can be changed by human impact
4. Nutrient loads reaching aquatic systems depend highly on the man-induced disturbances of the natural hydrological and ecological characteristics of the catchment
5. Intensity and duration of floods are modified by the biological characteristics of fluvial corridors, which in turn are modified by the hydrological regime
6. The nutrient status of rivers is influenced by ground water inflow and the biotic structure of the river valley
7. The transport and transformation of pollutants are highly influenced by the hydraulic–hydrological regime and by the ecological characteristics of fluvial corridors
8. The application of GIS-based ecohydrological approaches to subsystems of catchments consisting of ecotones and elementary patches, makes hydrological and ecological information gained in the microscale systems aggregable into higher levels of abstraction. The integration of this information into hydrological concepts will lead towards a more profound interpretation of the hydrological regime of catchments
9. Comprehensive understanding of ecohydrological processes and improving predictive ability form a basis for cost efficient management of water resources and landscapes
10. Optimization of the structure of ecotonal zones like riparian buffer zones, wetlands, or floodplains is the main tool for the reduction of nutrient transfer from the catchment to the river and other downstream recipients
11. Indices for predictive planning and sustainable management of aquatic resources should be based on point/local data and studies on large-scale hydrological processes

A comprehensive assessment of the surficial ecohydrological processes is the topic of Project 2.4 (UNESCO (1996), p. 20). It is meant to solve a global puzzle, providing a methodological framework that describes and quantifies through experimental research, the flow of water, sediments, nutrients, and pollutants in time and space under various climatic and geographic conditions. It includes nonstructural measures that use biotic elements in construction and management. Another objective is the improvement of the methodology for water ecosystem vulnerability assessment.

1.2. Ecohydrology

The objectives of Projects 2.3/2.4 contributed to the discussion of many aspects of ecohydrology under a wider scope, which resulted in a ''New Paradigm for the Sustainable Use of Aquatic Resources'' (Zalewski et al., 1997). This is a conceptual background for working hypotheses (Table 1), and practical guidelines for the implementation of Projects 2.3/2.4.

Many aspects of ecohydrological interest are touched on in this publication (Table 1). Ecotones and ecosystem patches in particular are landscape elements of potential scale-integrating power, which may span the gap between point/local data and the catchment scale. The strong international demand for this IHP-digest was a positive marker for the high interest these ideas find in today's world of hydrology.

2. Reflections on the state of knowledge

Ecohydrology is a Janus-faced scientific complex. It integrates ecology into hydrological approaches, and hydrology into ecological studies,

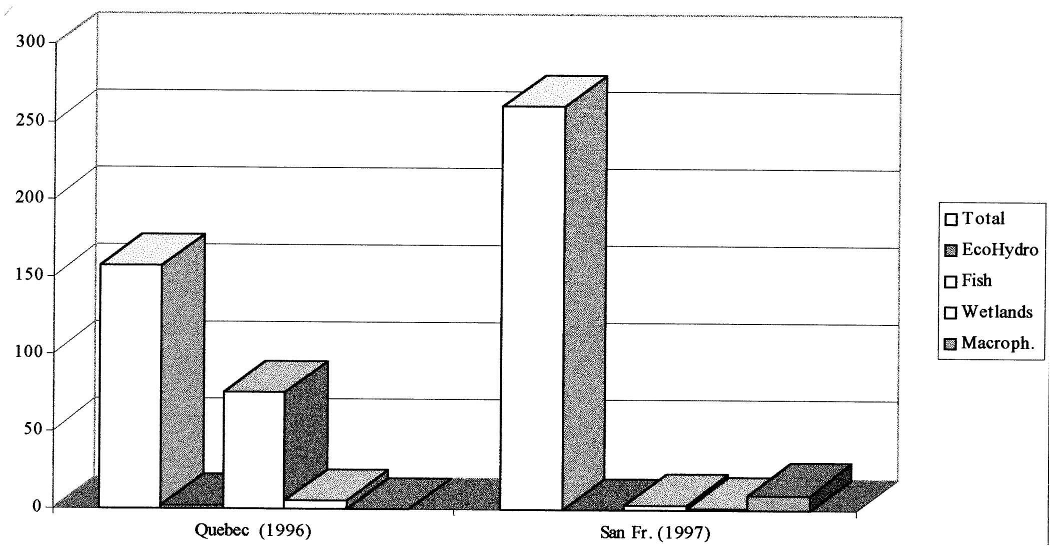

Fig. 1. Contributions per topic in two international conferences on ecological aspects in hydrology. Quebec, 1996: Ecohydraulics 2000. 2nd International Symposium on Habitat Hydraulics (Leclerc et al., 1996). San Francisco, 1997: Environmental and Coastal Hydraulics: Protecting the Aquatic Habitat (Holly and Alsaffar, 1997).

and it will lead towards a new set of information. To test the state of knowledge the proceedings of two recent international conferences were scanned. The conference in Quebec (Leclerc et al., 1996) dealt with habitat hydraulics, while in San Francisco (Holly and Alsaffar, 1997) hydraulics devoted to the protection of the aquatic habitat were the main objective.

Under the condition that genuine biological information is an indispensable ingredient of any ecohydrological study, several hundred contributions in both symposia were studied. A short overview is given in Fig. 1.

It is not questioned that most of the contributions dealt with ecological aspects, however, the number of publications really integrating biological information is rather small. All other cases deal with it as just an index or factor in a mathematical formulation, thus presenting no information on the biological item itself.

Ecohydrology was the topic of just two presentations in Quebec (Breil and Capra, 1996; Saint-Hilaire et al., 1996), but fish were of more interest in hydraulic/hydrological investigations (Baras et al., 1996; Jansen et al., 1996; Robert et al., 1996; Rowntree and Wadeson, 1996; Tsujimoto, 1996; Vehanen et al., 1996; Alfredsen, 1997). Wetlands are important hydrological elements with respect to their potential buffering capacity, yet there are only a few publications on the topic (Balogun, 1996; Mercier, 1996; Nottage et al., 1996). Hydraulic engineers studying the roughness conditions of canals or natural fluvial systems have an interest in the vegetation, mainly the aquatic macrophyte growth. The blackbox approach to this problem is quite well understood, but more detailed studies, and especially those that also provide information on the biotic composition of these roughness elements are scarce (Bernez and Haury, 1986; Stephan and Wychera, 1996; Fukuoka and Watanabe, 1997; Okabe et al., 1997).

In ecohydrology, information on biotic elements is a must. Species diversity, growth forms of vegetation, biomass estimates, etc. are items to be described in biologically relevant terms, to define the ecological value of the biotic elements as well as that of the whole ecohydrological study (Kouwen and Fahti-Moghadam, 1996; Tsujimoto and Horikawa, 1997).

A survey of the information derived from these two top international symposia revealed that the ecological aspect does not match the general themes. Sophisticated modelling attempts in hydrological and hydraulic studies may describe the effects of hypothetical biological structures, and biological elements may be included in some formulations, yet the real nature and the ecological quality of these objects cannot be estimated through such an approach.

On the other hand, it must be admitted that most biological investigations, which include hydrological and hydraulic aspects, are normally limited by the bank-full line, which is much too small a scope to reach the level of theoretical hydrology or hydrological management.

3. Concepts

A biologist will perceive only a vague picture of the concepts behind hydrology apart from the management of water resources through predictive models that limit the threats, and enhance the benefits of water in the human environment. Vice versa, the hydrologist may not have a clear picture of which aspects of biology should be included in his approach. To intensify the integration of ecological aspects into hydrology and to allow hydrologists to benefit from this knowledge in future investigations, a few hypotheses, concepts, and models on the ecology of fluvial systems are presented here. However, this is a very personal and probably non-comprehensive selection.

Odum (1957) described the energy budget of a large spring system in Florida, which gave a tremendous impetus to modelling freshwater — and terrestrial (!) — ecosystems. Another contemporary concept was biological succession (Margalef, 1960). With special reference to the typology of river stretches, Illies (1961) and Illies and Botoseanu (1963) described biozooenotic zones based on fish communities (see also: Huet (1954), Vannote et al. (1980), and Bornette et al. (1998)). A summary on river zonation and classification was presented by Hawkes (1975).

Observations in tropical rain forests and coral reefs introduced the idea that in many natural systems the high stability observed in the total system was based to a large extent on instability on the point scale (Connell, 1978). This is important with respect to all concepts concentrating on the properties of micro-habitats, which can show a high degree of variation without destabilising the whole system.

In 1980 a period of intensive theoretical discussion was triggered by a concept that still appears to be one of the (few) well-known concepts among a larger number of scientists, even those less closely interested in theoretical river ecology. Vannote et al. (1980) presented the river continuum concept (RCC): in natural river systems, biological communities form a temporal continuum of synchronized species replacements following the flow from the spring to the river mouth. Even among engineers this concept is sometimes known, although in most cases only the attention-catching name is recognized.

The RCC looks exclusively at pristine rivers, and these are rarely found in man-impacted landscapes. One concept taking into account human uses was the serial discontinuity concept (SDC) by Ward and Stanford (1983). At about the same time scientists became aware of the role of woody debris changing the flow of rivers and a large number of investigations were then devoted to this subject (Triska, 1984).

Cummins et al. (1984) started a process of changing, reshaping, and extending the RCC to transgress and enhance the confined field of application of this valuable contribution to stream ecosystem theory. Minshall et al. (1985) extended the RCC in a refining process, which led to encompassing broader spatial and temporal scales. While the experience of some authors lay close to the main line of the RCC, and they tried to find special applications and extensions to the original concept, authors working with different types of rivers strongly asked for a general revision for the whole concept, e.g. Statzner and Higler (1985), who advocated drastic modifications of the theoretical background of the RCC.

Another theory with high impact on the scientific community was triggered by the very special properties of the object under observation: the conditions of the Amazon River definitely limited the application of the RCC to such an extent that a new hypothesis was worked out by Junk et al. (1989). The enormous flood plain of the largest river of the world and its peculiar hydrological regime presented the background for the flood pulse concept (FPC). It takes into account that the productivity of the riparian forest can greatly modify patterns of ecosystem processes that were predicted earlier by the RCC. The fact that river zones may take on a life of their own was quickly accepted on a wider scope and led to questioning the RCC and its basic hypotheses (Sedell et al., 1989).

With studies on carbon resources for river organisms, another component was taken into account: the riverine productivity model (RPM) by Thorpe and Delong (1994) stated that organic carbon in a river is derived from a combination of (i) local autochthonous production, (ii) direct inputs from the riparian zone, and (iii) instream primary productivity, a factor not previously much respected in the ecology of fluvial systems

The approaches above focused more or less on natural rivers, yet in many cases river reaches are heavily modified by regulation and human use of water resources, even in developing countries. The connectivity between the main river channel and aquatic habitats in the flood plain was soon realised as a driving factor for all processes in the fluvial system. Ward and Stanford (1995) focused on the disruption of connectivity by any measures of flow regulation. Petts and Amoros (1996) pointed out that channels may be progressively disconnected not only by man but also by deposition resulting from geomorphical processes and ecological succession. Bornette et al. (1998) described in detail the diversity of aquatic plant life with respect to the role of connectivity for flood plain water bodies: all these approaches can be summarised as the connectivity concept (CC).

Through all these concepts biologists have described the ecological aspects of the situation in pristine rivers as well as the role of human interaction within these systems. In principle, the same aspects are the main objectives of the hydrologist's tradition. Yet, there is little knowledge of the one discipline's concepts by the other. One of the main tasks of IHP-V, Projects 2.3/2.4 must be the transfer of knowledge across the gap still existing between both sciences involved in ecohydrology

4. Scales

Problems of scaling exist both in hydrology and ecology. In many cases it is hard to extend the results from one scale to another. The problem starts with terminology. The numerical dimension of terms like point scale, catchment, meso, macro, or mega-scale are not defined within each field, and more deviation can be found when comparing the meaning of these terms between ecology and hydrology. There is no doubt that many studies intended to solve scale problems. The approach of Sloane et al. (1997), in the perception of the authors, differs from others, as they attempted to keep to a minimum any assumptions made about the physics, etc., above the scale at which the process descriptors were known to be valid. The hydrological elements ('UP-elements') used by the authors would be typically applied to basins of which the surface area was in the order of about 100 km^2. It is clear that a minimum element area of this order should have biological landscape elements compatible with this scale. But where would elements usually investigated by limologists fit into this scale?

Following Bovee (1996), who propagates a top-down strategy for habitat suitability criteria focusing at the 'meso-habitat' scale, which may reduce the need for high precision sampling techniques (e.g. observing, habitat use by snorkelling) a terminology problem clearly exists. This is more pronounced when ecologists concentrate on the investigation of processes and communities in habitats and ecotones, which may present far less than a point-scale investigation to the hydrologist. Meso scales in biology may be the fluvial corridors or ecotone complexes or mosaics of ecosystem patches, whereas the macro-scales in ecology may reach the size of land-use types or ecosystems. In a hydrological view, however, these elements may be just sub-units on the catchment scale.

One of the most definite needs in ecohydrology is to collect only data sets that can be used in the scales of both scientific fields intended to have interdisciplinary interference. If habitat conditions are to be described by the hydrologist, the size of the unit element must be reduced to the physical size of the ecological element, e.g. the number of gauges and the period of readings must be increased dramatically in a rather small area. This is especially important in connectivity studies when trying to find a hydrological background for the changes found in the natural plant and animal communities.

If the ecologists want to provide data for the hydrologists black box on the catchment scale, they will have to aggregate habitat relevant data to the scale of ecotone complexes or a sort of differentiated land-use type information. One possibility to intensify these approaches is the use of geographic information systems, which will aggregate information derived from the point scale to the unit element during the GIS approach.

With respect to the scaling problem, definitions and data must be integrated from the very beginning of genuinely ecohydrological studies. It also needs the extension of the ecological approach across the bank-full line into the adjacent landscape, which defines greatly the hydrological conditions in a river: in turn, these conditions are the basis for the biota living there.

5. The future of ecohydrology

The general problems mentioned above show the direction in which to proceed: fundamental studies should be directed to learning what the basic concepts of fluvial systems are in hydrology and ecology at present, and how they can be matched. This will provide a common starting point from which to develop unified concepts and ideas.

With respect to scales the terminology should be less confusing and more strictly defined: numerical equivalents of what a term means in the view of each researcher should be provided in all publications. This would make comparisons easier and would greatly add to the unification of theories and approaches. The organisation of typology, although often discriminated against as over organization, is essential in this case.

Within the scales used by hydrologists or ecologists at present, information to be provided by the partner's field should be defined. Convergent concepts instead of diverging working hypotheses and projects will be the result.

To achieve these goals it will be necessary to start integrated research with all partners in an interdisciplinary network, which is the aim of IHP-V. Interdisciplinarity always starts at the beginning of a study, or it will never be achieved in the same quality. The workshop on ecohydrology in Lodz is another step forward in this direction and it must be seen as a new impetus for ecohydrology.

6. Summary

The present situation in the sciences dealing with water is obviously shaped by the acceptance of the necessity to co-operate. Many projects try to enlarge their confined vision with aspects of either an hydrological or ecological nature, to come closer to the ideal of ecohydrology and to brush up their own limited approach. In spite of this development there is a definite lack of interdisciplinarity. The concepts of hydrology and ecology must be integrated on a much broader basis. The same applies to the scales where new tools like GIS may help to find a common language and common results. This will lead to including new scientific aspects into more traditional assays, which means that new members will have to be integrated into the scientific teams. Most important, interdisciplinarity from the very beginning should be the normal procedure. In the end, 'pure' science will have to tackle applied problems to a larger extent, otherwise "politics will happen, whether or not science provides input" (Perry, personal communication).

With respect to the hypotheses collected in the Ecohydrology-Digest (UNESCO, 1996) slow but positive progress is seen: historical changes in the fluvial corridors as a basis for the understanding of present situations and the predictions of future changes are slowly becoming an objective in special projects. Processes of resistance, resilience, and buffering capacity are the main points of interest in a number of present studies. Part of this information goes along with the enhancement of knowledge on the vulnerability of riverine landscapes under human impact. Aspects of water discharge, nutrient, and pollutant loads, as well as the processes of groundwater inflow are not yet so well covered in hydrological studies with respect to their ecological characteristics. The addition of information on species diversity, structure of vegetation, and other genuinely ecological information is one of the prime necessities at present.

Management dealing with the optimisation of the structure of ecotone zones in flood plains and in the whole catchment usually fights a lack of space for ecohydrologically relevant structures, and a lack of funding, although ecotones and other structural biotic elements provide the basis for sustainable landscape management. It should be an issue of prime interest to point out the monetary benefits on the large scale that can be reached through ecological optimisation. Yet, the present state of knowledge is far from providing enough input to make decision makers act accordingly. GIS-based studies may help to develop multifactorial indices comprising both ecological and hydrological information necessary to convince politicians as well as the public.

However, all present approaches uniting efforts to match hydrology and ecology indicate a strong move towards real ecohydrology and, in my opinion, the main goals of Projects 2.1/27.4 of IHP-V can be reached.

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