RIVER ECOSYSTEMS

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Contents

Summary

Although longitudinal linkages played a most important role in the early thinking on the river as an ecosystem (River Zones Concepts, River Continuum Concept) there is un urgent need to replace this longitudinal paradigm for the 4 dimensional one and to considering the whole river basin context (e.g. as proposed by Ecohydrology Concept - EHC).

There is a growing body of evidence that the results of human activity in the different parts of a river ecosystem and its watershed can significantly affect the functioning of other remote parts of the system, and can be harmful for biota and human beings.

Management and restoration strategies should thus apply ecohydrological methods based on feedback between abiotic and biotic components of catchments, and their synergistic action. Attention should be paid to adaptation of chosen management strategies according to special attributes and dominating processes in each catchment.

The integration of the different ecosystem biotechnologies at the river basin scale might generate a positive synergetic effect between all its components: riparian ecotones, wetlands, floodplain, trophic pyramids and nutrient spirals, resulting in improvement of water resources quality and quantity.

From the point of view of water quality improvement, application of biotechnologies converts nutrients from inorganic to organic forms and transfer from dynamic to unavailable pool in a landscape scale, thus preventing freshwater eutrophication.

From the point of view of hydrological advantage, development of diversified landscape and natural hydrological connection between a river and its catchment significantly increases water retention in the catchment, stabilizes the hydrological parameters of the river and diminishes extreme hydrological events.

1. Introduction

The degradation of freshwater ecosystems has been of a two-dimensional character: pollution and disruption of long-established water and biogeochemical cycles in the landscape. Both cause degradation of the biotic structure of catchments and freshwater ecosystems, and decline of water resources.

Pollution can be significantly reduced or eliminated by technological progress, but degraded water and nutrients circulation and disturbed energy flow at the catchments scale create complex problems.

Thus, the twenty-first century will become an era of integrative science, because understanding the complexity of our world is key to achieving sustainable development. This is particularly necessary in ecology and environmental sciences, for two reasons.

First, there is an urgent need for sound solutions toward declining ecosystem services and biodiversity at the global scale. Second, further scientific progress can be made by testing existing concepts and "know-how", and by implementing concepts and methods integrated at the large scale of basin landscapes.

2. Evolution of the scientific paradigms in river ecosystem ecology

The evolution of scientific paradigms in river ecosystem ecology can be described by distinguishing the main approaches defined in key conceptual publications of the twentieth century, along the time axis of Figure 1 (See also Appendix 1).

The vertical axis of the Figure consist of inspiring oscillations between holistic concepts (paradigms), e.g. the River Continuum (Vannote *et al.* 1980), and reductionist experimental tests, and developments e.g. the interbiome comparison of stream ecosystem dynamics (Minshall *et al.* 1983). This continual interplay can be considered as a major force driving our progress in understanding river ecosystems.

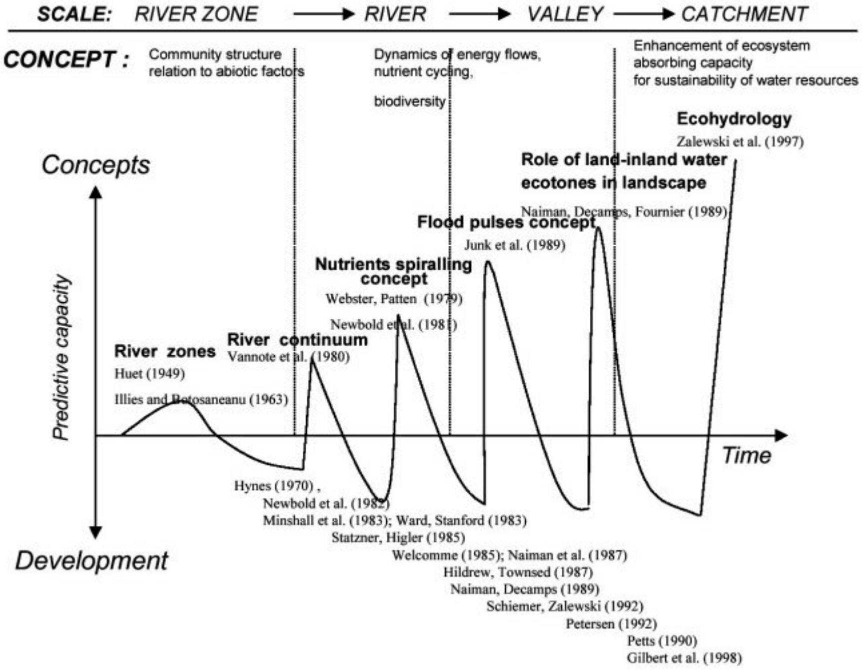

Figure 1. The interplay between a holistic concept and reductionistic experimental tests and developments as a driving force of progress in knowledge about ecology of river basin (after Zalewski 2000b, changed).

Superimposed on a temporal scale, the scope of thinking about river ecosystems has been broadened from the river zones to the river continuum, then to the rivers and their valleys, and finally to the river basin as an Ecohydrology Concept. In parallel with this shift in thinking, the river ecosystem scientific approach has been under development through the generation of three key hypotheses:

- the community structure and its relation to abiotic factors (e.g. slope);
- the dynamics of energy flow, nutrient cycling and biodiversity, and
- the functional relationships between hydrology and biota for control of ecosystem processes - ecohydrology.

Attempts to place fragments of knowledge of the structure of the riverine biota into a holistic framework started with Shelford in 1911. But the first effort to integrate the biological structure of fish communities as a function of abiotic hydrological factors (river slope velocity) was proposed by Huet in 1949. A large step which exceeded the actual level of advancement of river ecology was proposed by Hynes (1970)—that rivers should be analyzed from a watershed perspective. The next serious development occurred as a shift from "structural" thinking (species composition in river zones) to "functional" thinking (production to respiration ratio) in the holistic framework of the River Continuum. This was extended by the concepts of nutrient spiralling (Webster, Patten 1979) and the flood pulse (Junk *et al.* 1989). All these ideas were defined through syntheses of experimental and conceptual efforts, and some of the most notable are detailed below the lateral axis of Figure 1.

One might be considered especially in relation to the genesis of Ecohydrology (Zalewski *et al* 1997). Zalewski and Naiman (1985) suggested, considering the regulatory mechanisms for fish communities in rivers, that "abiotic factors (hydrology) were of primary importance in most situations but when the environmental conditions approach the physiological optimum for fish and become stable and predictable, the role of biotic interactions gradually increases" (the Abiotic-Biotic Regulatory Concept). A substantial change, expressing a new proactive attitude in ecological/environmental thinking, brought also the consideration of the role of the landscape in mitigating human impacts—namely, managing land/water buffering zones (UNESCO MAB Programme). For the first time this concept of the manipulation of the structure of the biota (ecotones) was considered for management, restoration and implicitly for conservation. All above efforts created the background against which the Ecohydrology Concept was formulated and developed over the lifetime of UNESCO IHP-V, 1997-2001. The concept provides a holistic integrative and interdisciplinary approach for scientific research and watershed management.

3. Ecohydrology – an integrative and interdisciplinary approach for scientific research and watershed management.

In the face of increasing pressure on freshwater resources, there remains an urgent need for new practical tools to achieve their sustainable management. Traditional water management does not consider the use of ecosystem processes as a potential management tool. For the above reasons, the UNESCO International Hydrological Programme (IHP) initiated an integrative theme of activities to achieve an increased understanding of hydrological and ecological processes in water ecosystems. This was defined as "Ecohydrology". **Ecohydrology is a sub discipline of hydrology focused on ecological aspect of hydrological cycle.**

As far as hydrological cycle posses the terrestrial and aquatic phase, which by specific methods differs, it should be distinguish in literature as the terrestrial and aquatic ecohydrology.

Terrestrial phase focuses on water-plant-soil interactions (Eagleson 1982, Bird & Wilby 1999, Rodriguez-Iturbe 2000). Aquatic phase integrates progress in limnology and oceanography (coastal zone ecohydrology) into hydrology for problem solving in water management (Zalewski *et al.* 1997, 2000, 2002; Wolanski *et al*. 2004).

During the genesis of ecohydrology, it was concluded that the key questions to integrate biota and hydrology should meet the two following fundamental conditions:

1. They should be related to the dynamics of two entities in such a way that the answer without consideration of one of the two components (both ways E↔ H) would be impossible. In other words, this question should enable the defining of relationships between hydrological and biological processes in order to obtain comprehensive empirical data at the same spatial and temporal scales.
2. The results of the empirical analysis should test the whole range of processes (from molecular to catchment scale), should enable their spatial/temporal integration, and

should be convertible to large-scale management measures in order to enable further testing of the hypotheses.

Taking into account the above conditions, the key questions for ecohydrology have been defined based on an in-depth understanding of the interplay between biological and hydrological processes and the factors that regulate and shape them. The hypotheses have been defined in the form of the following statements:

Hypothesis H1: "The regulation of hydrological parameters in an ecosystem or catchment can be applied for controlling biological processes".
Hypothesis H2: "The shaping of the biological structure of an ecosystem(s) in a catchment can be applied to regulating hydrological processes".
Hypothesis H3: "Both types of regulation integrated at a catchment scale and in a synergistic way can be applied to the sustainable development of freshwater resources, measured as the improvement of water quality and quantity (providing ecosystem services)".

It should be stressed that according to the Ecohydrology Concept, the overall goal defined in the above hypotheses is the sustainable management of water resources. This should be focused on the enhancement of ecosystem carrying capacity for ecosystem services and anthropogenic stress. Such an interdisciplinary, integrative approach provides the background to convert environmental threats into sustainable development. So far, the dominant approach in environmental management, based upon descriptive science, over-engineering of the natural environment and often spatially restricted environmental conservation, leads to continuing global environmental deterioration. A solution to this dilemma requires both technical and environmental sciences. The target for technical sciences has been recently suggested by Von Weizsacker *et al.* (1997), as ‘a factor of 4’. This means the technical capability exists to reduce by four times the use of energy and raw materials per unit of growth per capita. This will substantially reduce emission of pollutants to the environment but maintain progress in living conditions for global population. This solution alone is not sufficient because of the scale of the degradation of our planet’s hydrological and biogeochemical cycles. Environmental science needs both a target and a means of achieving it. The progress in understanding the functioning of ecosystems over the last 10 years has improved our understanding of ecological processes (e.g.,), to the point where we can use feedback mechanisms for ecosystem management using ‘ecosystem engineering’ (Mitsch 1993). Ecohydrology is a new paradigm which attempts to do this. It suggests that the sustainable development of water resources has been dependent on ability to maintain evolutionarily established processes of water and nutrient circulation and energy flow in the basin scale. A profound understanding of a whole range processes has a two-dimensional character: first, temporal, from past (paleohydrology) to the present and considering future global change scenarios, and second, spatial, by understanding the role of aquatic and terrestrial biota in water dynamics in the full range of scales from molecular to the catchment. Both dimensions should serve as a reference system for enhancement of the absorbing capacity of ecosystems against human impact by using ecosystem properties as management tools. This in turn depends on the development, insemination and implementation of interdisciplinary knowledge based on recent progress in environmental sciences.

The Ecohydrology principles and key assumptions

As a result of the efforts of international teams of limnologists and hydrologists cooperating during International Hydrological Programmes V and VI (IHP V and IHP VI) the three principles which define ecohydrology and its three key assumptions were formulated (Zalewski *et al.*1997). The starting point for the Ecohydrology Concept became, already investigated and described, the hierarchy of factors which regulate ecological processes (implicitly water quality), in rivers of different sizes and in different climatic zones (Zalewski & Naiman, 1985). This assumption, valid for both ecologists and hydrologists – especially due to the reason that the abiotic, hydrological regulation is the primary one, allows definition of the three principles of EH and to elaborate its key assumptions (Zalewski, 2000, 2006).

Ecohydrology Principles:

1. “Hydrological: the hydrological cycle at the basin-scale should be considered as the template for quantification of both impact and opportunities relevant to the biological performance of the ecosystem”.
2. “Ecological: freshwater ecosystem robustness can be enhanced on the basis of understanding the evolutionary established resistance and resilience of the ecosystems”.
3. “Ecological engineering: enhancement of ecosystem resistance/resilience can be achieved by “dual regulation”—biocoenosis by hydrology, and vice versa. Thus by shaping the biota, the hydrology—mostly water quality—can be improved”.

The large potential of knowledge which has been generated by dynamic development of ecological engineering (Mitsh 1993; Jorgensen 1996) should significantly accelerate implementation of the EH concept.

Ecohydrology key assumptions:

1. ”Dual Regulation” of hydrology by shaping biota and, *vice versa*, regulation of biota (e.g. elimination of toxic algal blooms) by altering hydrology (e.g. Zalewski *et al.* 1990).
2. Integration: at the basin scale various types of regulations (E↔ H) should be integrated towards achieving synergy to stabilize and improve the quality of freshwater resources at a basin scale (e.g. Zalewski 2000a).
3. Harmonization of ecohydrological measures with necessary hydrotechnical solutions (such as dams, irrigation systems, sewage treatment plants, levees at urbanized areas etc., (e.g. Timchenko 2001).

All three ecohydrological principles are illustrated in Figure 2, where for the reduction of eutrophication in temperate reservoirs, different ecological processes in the river basin have been integrated towards reducing phosphorus input and the reduction of its dynamic pool.

Thus, starting from the top of the catchment, the first stage has to be enhancement of nutrient retention within the catchment by: reforestation, creation of ecotone buffering zones and optimisation of agricultural practices. The buffering zones at the land/water interface reduce the rate of ground water flux due to evapotranspiration along the river valley gradient. Nutrient transformation into plant biomass in ecotone zones may further reduce the supply into the river channel. The wetlands in the river valley form a buffering zone as well, reducing the mineral sediments, organic matter and nutrient load transported by the river during flood periods, through sedimentation. Also in artificial wetlands, nitrogen load can be reduced significantly by regulation of the water level to stimulate denitrification through anaerobic processes.

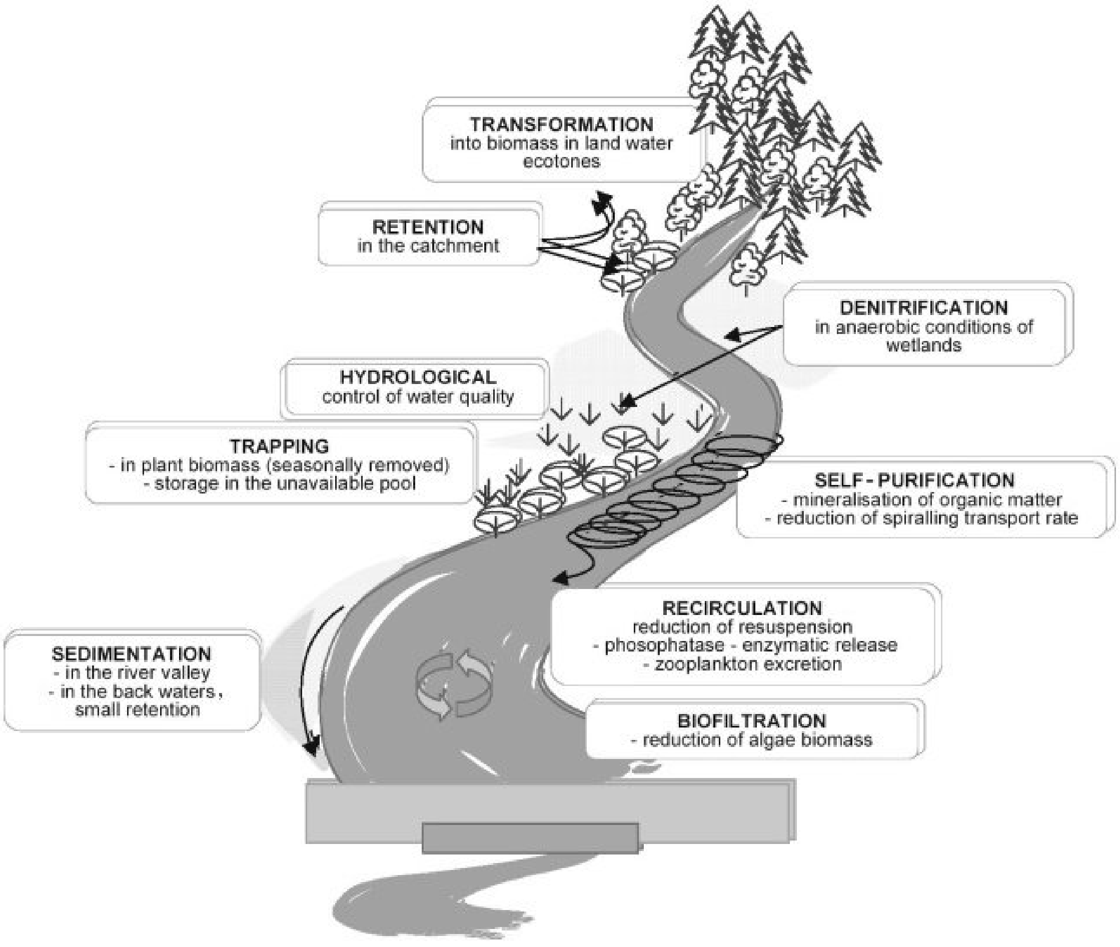

Figure 2. An example of synergistic interactions between different processes to enhance capacity of the river basin for self-purification. Source: Zalewski 2000a, changed.

Traditional sewage treatment plants in a small town usually do not possess a sophisticated tertiary chemical treatment stage due to the high costs of construction that local communities cannot afford. They reduce BOD and some nutrients but still negatively influence water quality, reducing the benefits of rivers and reservoirs and their recreational values. Thus, extending sewage treatment by constructing a wetland results in more efficient reduction of pollutant loads and generates additional societal benefits. Improvement of water quality increases the appeal of water resources for tourism, which contributes to the inflow of capital to a region Moreover, the establishment of multi-species willow plantations in wetland areas, using species of local origin and those tolerating the high ground water level, maintain high river valley landscape diversity and provide an alternative source of energy (bioenergy) that can also help to reduce CO_2 emissions from burning fossil fuels. Moreover the ash can be used to fertilize forest plantations. In this way, the pollutants are converted into bioenergy. Producing bioenergy and timber also generates new employment opportunities and revenue flows while reducing capital outflows for fossil fuel use. Bioenergy can be used for conversion of non-degradable plastic wastes, by low energy technology, into paraffins, thus linking water and waste management. The use of ecological knowledge, therefore, results not only in a good quality environment but also can help to elevate the economic status and level of sustainable development in local communities. Such an implementation case, as a UNESCO/UNEP demo site, has recently been under development at the town of Przedborz on the Pilica River, a western tributary of the Vistula River, above Sulejow Reservoir in Poland.

In shaded rivers with a high nutrient load, it is possible to greatly amplify the self-purification capacity by creating an intermediate complexity of riparian ecotonal vegetation.

If, despite all the above measures combined with sewage treatment, the nutrient concentrations in reservoirs are too high and potentially might develop into toxic algal blooms, there are numerous methods to reduce recirculation of nutrients in reservoirs by locking them into the biomass of macrophytes, and translocation between trophic levels (e.g. biomanipulation).

Since the properties of large scale systems, as presented in Figure 1, cannot be predicted from the properties of its component elements, thus, such a complex strategy for restoring and controlling nutrients in the catchment landscape and freshwater ecosystem should be assessed continuously at every stage of its implementation, constantly adjusting to maximise the potential synergistic effect.

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Zalewski, M., and Hickley, P. [Eds]. (2004b). *International Journal of Ecohydrology & Hydrobiology*, Vol 4, No 4. Proceedings of the International Symposium "Ecohydrology and Physical Fish Habitat Modifications in Lakes", (UNESCO IHP-VI, EIFAC FAO), Mondsee (Austria), 26-28 November 2003. [the papers in this issue present the development of Ecohydrology Concept in context of fish communities and lake ecosystems]

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Zalewski, M. (2006). Flood pulses and river ecosystem robustness. Frontiers in Flood Research / Le point de la recherche sur les crues. IAHS Publ. 305:143-154. [this paper review the potential for application the ecohydrological approach to enhance flood plain robustness]

Biographical Sketches

Maciej Zalewski, Ph.D.1977, D.Sc.1988, Professor Titular 1993.

Main Research Areas:

Application of Ecohydrology concept for restoration and renaturization of river systems and reservoirs, on the basis of analysis of processes from the molecular (enzymatic mechanisms compensating for shortage of phosphorus) to the catchment scale, with application of GIS techniques.

Professional experience:

Director of International Centre for Ecology, Polish Academy of Sciences

Director of the European Regional Centre for Ecohydrology (ERCE) under the auspices of UNESCO. PAS, UL, in Lodz, Poland (since May 2006)

Head of the Department of Applied Ecology, University of Lodz

Member of Scientific Council of Regional Bureau for Science for Europe ROSTE (UNESCO), Chairman of the Steering Committee of UNESCO IHP Programme "Ecohydrology", Project 2.3/2.4., Editor of International Journal "Ecohydrology & Hydrobiology", Co-ordinator of Polish Net of International Long Term Ecological Research (ILTER), Representative of UNESCO IHP to Scientific Committee on Water Research (ICSU, SCOWAR).

Iwona Wagner-, Ph.D. 2002 and M.Sc. 1995.

Main research areas

Effect of hydrological processes on pattern and intensity of freshwater eutrophication, phosphorus cycling and trapping of nutrients in wetland ecosystems, sedimentation in lowland reservoirs. Application of Ecohydrology Concept for restoration and management of river systems and reservoirs.

Professional experience

Scientific Secretary of the UNESCO IHP-VI Project on Ecohydrology, co-operation with International Environmental Technology Centre of United Nations Environment Programme (UNEP-IETC)

1996 – 2001: Scientific Secretary of the UNESCO IHP-V 2.3/2.4 Project on Ecohydrology; Participation in organization of 6 national and 5 international conferences and courses.

Participation in International Projects

2002 – 2003: Integrated Large Scale Interbasin Demonstration Site: Application of Ecohydrology and Phytoremediation for Water Resources Management and Sustainable Development. Co-operation with UNESCO, UNEP.

2000 – present: Application of a lowland river floodplain for improvement of water quality in a lowland reservoir. Co-operation with Department of Geoscience, Frankfurt am Main University, Germany; Warsaw University.

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Education: Ph.D 1997 Thesis: Space as a limiting factor for fish communities in lowland and upland river systems. University of Lodz, Poland.

*Main Research Areas:*River ecology, biological assessment, fish ecology.

Participation in grants and projects:

2005-2008: AQUA-TNET, Socrates Thematic Network for Aquaculture, Fisheries and Aquatic Resource Management. Network for Education and Training in the Aquaculture Industry2002-2005: SOCRATES/ERASMUS New Curriculum Development (CD) European Union Project: Master of Inland Water Quality Assessment – contract no.: 29369-IC-1-2002-1-SE-ERASMUS-PROGUC-1.

2001-2004: Development, Evaluation and Implementation of a Standardized Fish-based Assessment Method for the Ecological Status of European Rivers (A Contribution to the Water Framework Directive) - contract no.: EVK1-CT-2001-00094. Acronym FAME.

1991-1994 Role of land/inland water ecotones in functioning of riverine ecosystem. Provided by Polish Committee of Scientific Researches.

1991-1994 Restoration ecology of two percid fishes. Provided by Agency for International Development (USA).