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Original Research Article

Ecohydrology: process-oriented thinking towards sustainable river basins

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ABSTRACT

Regarding recent progress in climatic change, the decline of water resources, degradation of soils and changes in demographic dynamics, this paper postulates that attempts to maintain the good ecological status of the biosphere based on the classic paradigm of nature-oriented thinking, embodied by conservation and restoration of nature, have to be expanded by environmental process-oriented thinking. Insofar as water has been a major driving factor of biosphere evolution and productivity, any profound understanding of fundamental ecological processes, such as hydrology and nutrient (C, N, P) cycles, on the scale of entire basins should be based on highlighting the biota response to various water pulse patterns in certain geographical regions, understanding of the role of biotic structure and the interactions present in shaping water and nutrient dynamics. This knowledge of ecohydrology principles provides the scientific background for regulating the processes and interactions for: enhancing water resources, maintaining and restoring biodiversity, providing ecosystem services for societies and building resilience to climatic and anthropogenic impacts (WBSR), from the molecular to landscape scale. The above four goals will be instrumental in the harmonization of biosphere potential and satisfaction of the needs of humanity postulated during EcoSummit 2012 and expressed in the Columbus Declaration. Process-oriented thinking should create the fundamentals for the integration of ecohydrology with environmental biotechnologies, hydro-technical and civil engineering.

1. Introduction

Water is the driving force of nature – *vetturale di natura* – Leonardo Da Vinci.

The term Anthropocene describes the leading role played by man in the modification and degradation of the biosphere, of which one of the major consequences has been the decline of ecosystem services, first and foremost water and food provision (Lal, 2013). This, combined with changing demography dynamics, may lead to local, regional and global conflicts.

Hence, one of the key challenges for science of the XXI century is obtaining a profound understanding of the cause–effect relationships between abiotic factors, such as hydrology and temperature, and biotic factors in all types of ecosystems, and their relationship with social dynamics from the perspective of (1) impact and risk assessments, (2) prevention of ecological potential degradation, measured by biodiversity, (3) enhancement of ecological potential of the ecosystem with the eventual aim of providing ecosystem services.

To provide solutions for such grave global environmental challenges, science has to continue its highly-specialised investigations, which are necessary to generate

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progress in biology, medicine and engineering, but greater efforts should be devoted to integrating the specialised knowledge of these particular disciplines through transdisciplinary methodological frameworks such as ecohydrology (Zalewski et al., 1997; Baird and Wilby, 1999; Zalewski, 2000, 2010; Acerman, 2001; Eagelson, 2002). Such an integrative approach evokes the classic Francis Bacon (Novum Organon, 1620) tenet that we can direct the nature only by listening to her. This, in turn, emphasises the need for development of low-cost advanced technologies based on the concept of the use of ecosystem processes as management tools (Zalewski, 2000). This is particularly important for solving the problems which appear in a broad range of highly-complex and modified ecosystems, which are under pressure from a range of social needs and priorities.

Transdisciplinary science should not only integrate various disciplines which, up to now, were focused mostly on testing hypotheses addressing a single aspect, but also aim to develop advanced hypotheses, which should express the complexity of the environmental processes associated with the problems to be solved. Traditional over-engineered water management measures, which have been focused on hydroenergy generation and prevention of floods or droughts, usually degrade the biological structure and functions of ecosystems. Transdisciplinary hypotheses when empirically tested on the mesoscale of the hydrological cycle at the river basin, should generate greater progress in science and enhanced sustainability by (1) deepening the understanding of ecological processes e.g. by identification and quantification of the potential synergies and antagonistic relationships between water processes, nutrient and pollutant cycles under various impacts, and (2) encouraging harmonization of societal expectations with ecosystem potential by enhancing the ecosystem services and raising the environmental consciousness of the society.

2. The Columbus Declaration—an action plan for the sustainable future of Spaceship Earth

The era of globalization has accelerated development and in general, improved the quality of life of humanity. However, the interconnected socioeconomic system has also accelerated and intensified the exploitation of natural resources, emissions, and degradation of environment. To reverse these trends, the Columbus Declaration, being the aftermath of the 4th International Ecosummit (http://www.ecosummit2012.org), proposes a four-step strategy. The first step is that (1) integrative interdisciplinary research must be enhanced to provide a better understanding of the cause-effect relationships within the paradigm of globally-integrated system cycles, and in order to increase their predictive potential. This will create a background for (2) policy harmonization to better understand the linkage between nature and society, and in turn, reduce further disturbance of the planet's biological productivity, biodiversity and biogeochemical cycles. The next necessary step towards reversing the incurred damage should be (3) the development and application of innovative and novel ecological design principles recently incorporated by ecological engineering, ecological restoration and ecohydrology. Finally, (4) education and values should be addressed. It has been emphasized that society's lack of understanding of the global environmental system, combined with demographic change and increasing resources use, accelerates the unsustainable use of resources. Lifelong learning, as well as a grounding in ethics and cultural appreciation should create a background for better integration of society and nature.

3. The need to enforce the structure-oriented actions by process-oriented thinking in environmental sciences

The awareness of the necessity for nature conservation has its roots in both the industrial era, as a counter to the intensive exploitation of natural resources, and progress in biological sciences, especially an appreciation of the determinants and values of biodiversity detailed by Linneus (1753), Darwin (1859), Cuvier (1812) and Buffon (1852). The greater exploitation of natural resources during the industrial era and the consequential degradation of the ecosystem, together with progress in understanding the determinants and dynamics of ecological succession (Clements, 1916) forms the background for restoration ecology. This discipline has become especially relevant for such patches of landscape as post-mining sites, urban space or degraded soils in agricultural land.

However, why in the XXI century is restoration ecology not sufficient to halt the progress of environmental degradation? The two key reasons are demographic and economic. While during the latter half of the XX century, over the last six decades, the population has increased almost 3-fold from 2.5 to 7 billion, global GDP has increased 10-fold from 5.3 billion to 55 billion as a consequence of dramatically-increased exploitation of natural resources, with especially grievous consequences for water and soil: prime agricultural soil is a finite resource and most of it has already been appropriated by the agroecosystem. Hence, the per capita availability of soil and water resources is extremely low and decreasing (Lal, 2013).

Although the presence of natural ecosystems containing a high biomass of plants is an important regulatory factor of the hydrological and nutrient cycles, a large part of the global landscape, apart from deserts, high mountains and the boreal zone, has been converted to agricultural land during the Anthropocene era. A consequence of the reduction of biomass and soil organic matter is the modification of the hydrological cycle away from one where the biological component stabilizes the hydrological dynamics and heat budget at a level favourable for plants. Additionally, as a diversified plant biomass efficiently reduces the leakage of nutrients from terrestrial to aquatic ecosystems (Naiman and Decamps, 1990) and to coastal zones, both water and temperature conditions at catchments with high plant biomass are maintained at intermediate disturbance level, reducing the probability of catastrophic droughts and floods, high carbon storage and low nutrient loss to aquatic ecosystems.

The simplest potential solution, the restoration of agricultural land in primaeval forests (Fig. 1), is not realistic due to demographic and economic dynamics; for