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The Science of Flow-Ecology Relationships: Clarifying Key Terms and Concepts

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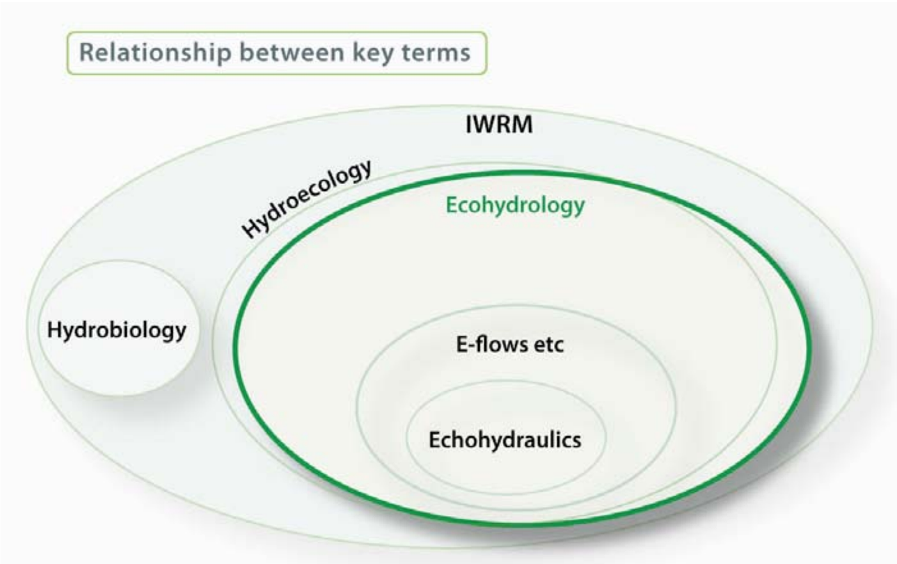
Introduction

As any visit to an international 'Water Forum' would attest, the proliferation of terminology, acronyms, and interrelationships associated with water-related concepts and programs can be overwhelming. It is widely acknowledged that fresh waters are undergoing significant changes in response to human use and climate change (e.g., Dudgeon et al. 2006). As a result, several complementary concepts have emerged to better understand and address the human and environmental consequences of these fundamental changes to the global water system. Along with the development of these concepts has been an emergence of many new terms, some with apparently overlapping definitions – thereby confusing investigators and managers alike.

In this short communication, we identify the relationship between five of the more widely known concepts – Integrated Water Resources Management (IWRM), Hydroecology, Ecohydrology, Ecohydraulics and Environmental Flows – and define the key terms and phrases used to describe them. In general, IWRM is a framework for water resources management, while Hydroecology, Ecohydrology, Ecohydraulics and Environmental Flows are branches of science that aim to support water management through improved understanding and quantitative representation of the relationships between hydrology, habitat, biodiversity and ecosystem function.

(1) Integrated Water Resources Management (IWRM) - A process promoting the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP 2000).

This is the broadest of the five concepts in that it describes a holistic approach to water resource management at basin to regional scales (see figure). IWRM aims to meet human water needs without compromising the sustainability of ecosystems, both because of the intrinsic value of ecosystems as well as the goods and services ecosystems provide to humans. IWRM calls for establishing supportive political and institutional frameworks for water management based on fundamental principles acknowledging the finite nature of water resources, the need for equitable stakeholder participation, the important role of women in water management, and the economic value of water. IWRM also offers a wide range of tools, or management instruments, that assist water managers in meeting management goals. Examples of key tools include re-articulation of water rights, institutional reforms, economic incentives, training and capacity building, and a host of technical and scientific approaches. Integrated Water Resources Management is intended to be an adaptive process, whereby management actions are modified in response to changing environmental, social, and political realities.



(2) Hydroecology – is the study of the bi-directional nature of hydrological-ecological interactions, including feedback mechanisms, at a wide range of spatial and temporal scales (from contemporary to palaeoecological-hydrological viewpoints; GEES 2006). Hydroecology seeks to discover and understand basic system properties and processes, using that knowledge in practical applications toward better management – but seldom at the larger watershed scales. Hannah et al. (2004) provide a thoughtful discussion of the relationship between the terms Hydroecology and Ecohydrology (see below) correctly suggesting that, at present, the meanings and activities behind the terms cannot be precisely separated. Nevertheless, Hydroecology is an accepted term, with a history of usage, that is virtually synonymous and contemporaneous with the term Ecohydrology as applied to aquatic ecosystems.

(3) Ecohydrology – There are two contrasting definitions of this concept; depending if viewed from an aquatic or terrestrial perspective.

Aquatic – Ecohydrology considers the functional interrelations between hydrology, aquatic ecosystem processes and their biota. It uses ecosystem processes as tools to meet freshwater resource management goals, such as enhancing natural processes of nutrient retention to avoid harmful algal blooms (Zalewski 2000). In effect, it proposes a 'dual regulation' of the system by simultaneously using ecological and hydrological processes to enhance the overall integrity of aquatic ecosystems in the face of human-mediated alterations (Zalewski 2006). Aquatic - Ecohydrology does not specify the method of incorporating ecosystem processes into management programs, as that is necessarily site specific. As part of the strategy, it focuses on understanding useful ecosystem processes and aims to communicate that understanding to water managers in a way that enables incorporation into planned and existing programs.

By applying new understandings emerging from ecohydrological research as tools in IWRM, water managers can enhance the resilience of freshwater ecosystems to human impacts, thereby capitalizing on ecosystem services and achieving water management goals with minimal engineering inputs and financial investment. The Ecohydrology perspective is based on the assumption that sustainable management depends on the restoration and maintenance of established fluvial processes, nutrient cycling, and energy flows (Madsen et al. in press). To date it has been largely applied in the control of pollution in lakes, large reservoirs and rivers through the controlled manipulation of water regimes (e.g., Zalewski et al. 2000; Wagner & Zalewski 2000) but Ecohydrology has the potential to become broader and more effective by incorporating fundamental social and cultural considerations into the process.

Terrestrial – Ecohydrology is a sub-discipline of hydrology that focuses on ecological processes involved in the hydrological cycle. These processes generally occur within the soil and canopy, and so emphasis is put on transpiration and thermodynamic energy balance at the land surface (Wikipedia 2006a). Although an important concept, it is clearly distinguishable from IWRM, Hydroecology, Aquatic-Ecohydrology, Ecohydraulics and Environmental Flows, and we need not consider it further for this discussion.

(4) Ecohydraulics – is the study of the linkages between physical processes and ecological response in rivers, estuaries and wetlands (CER 2006). Ecohydraulics is similar to Ecohydrology in the sense that it is an interdisciplinary approach attempting to integrate the work of engineers, biologists and chemists.

(5) Environmental Flows (E-flows) or **Environmental Water Allocations (EWA's) –** Historically, these phrases referred to the minimum flows of water (by volume and season) necessary to maintain aquatic biota and ecosystem processes (Tharme 2003; NSW EPA 2006). There is growing recognition, however, that many attributes of the natural flow regime need to be considered (Poff et al. 1997; Bunn and Arthington 2002) and this new scientific perspective has led to a broader definition of environmental flows. Until recently, in China and perhaps other Asian countries, we understand that these terms have related primarily to the flows required to flush river systems and restore water quality. In these regions, the western concept of 'Environmental Flows' is nowadays represented by the terms 'ecological and environmental water requirements' (EEWR), 'ecological water demand' and 'eco-environmental water consumption' (Song and Yang 2003).

In their broader sense, 'Environmental Flows' or 'Environmental Water Allocations', refer to the water regime of a river, wetland or coastal zone necessary to maintain the biophysical components, ecological processes and health of aquatic ecosystems, and associated ecological goods and services (Arthington et al. 2006). The phrase 'Environmental Water Allocations' is used primarily in Australia (though see Tharme

2003; Smakhtin and Shilpakar 2005), and is used to deliberately acknowledge the provision of specific amounts of water with particular timing, frequency, duration and variability to sustain river ecosystems. It also reflects the need to provide allocations for inundation of wetland and floodplain habitats – as opposed to flowing water *per se* – and has in recent years extended even further, now embracing freshwater flows to estuaries and coastal zones (Esteves 2002; Loneragan and Bunn 1999). This reflects the recognition that estuarine and coastal zones are part of the aquatic continuum from source areas to the sea, and that important hydrodynamic, biogeochemical and ecological processes are sustained, in part, by freshwater flows into tidal areas.

The concept of Environmental Flows is rapidly developing into a suite of frameworks and tools for the protection and restoration of inland and coastal aquatic ecosystems. In effect, it has become a branch of Hydroecology/ Ecohydrology specifically concerned with flow regimes and their geomorphological and ecological outcomes – and a field of interdisciplinary science and management that forms a cornerstone for effective IWRM. In fact, environmental flows are already recognized as legally required flows in some parts of the world, especially when combined with the minimal needs of humans (Naiman et al. 2002; Dyson et al. 2003). As such, Environmental Flows is a broader field than Ecohydraulics but is still a sub-discipline of Hydroecology/Ecohydrology.

(6) An Additional Term – One additional term requires explanation: Hydrobiology is the science of life and life processes in water. Much of modern Hydrobiology can be viewed as a sub-discipline of ecology but the sphere of Hydrobiology includes taxonomy, economic biology, industrial biology, morphology, physiology and related sciences. The one distinguishing characteristic being that all the topics above relate to aquatic organisms. The term is closely allied to limnology and can be divided into lotic system ecology (flowing waters) and lentic system ecology (still waters) (Wikipedia 2006b). Hydrobiology is more in the realm of discovery and understanding basic system properties and processes rather than in the practical application of knowledge about the system to better management. It is complementary to Hydroecology/Ecohydrology, Ecohydraulics and Environmental Flows activities, and provides useful technical guidance to IWRM programs.

Our Recommendations

We encourage the use of the phrase Integrated Water Resources Management (IWRM) as a necessary framework for managers to consider all interactions of humans with the water cycle. We believe that this effort will substantially improve sustainable management of water resources. Additionally, and in concordance with Hannah et al. (2004), we propose that 'Ecohydrology' be used as an umbrella term that is synonymous with Hydroecology, under which Ecohydraulics and Environmental Flows are encompassed as interrelated sub-disciplines. As a discipline, the generic term of Ecohydrology encompasses all aspects of research related to flow-ecology relationships. However, within this broad concept, we acknowledge that there is specific and overlapping interest in the study of Ecohydraulics and Environmental Flows – the deliberate allocation or manipulation of a water regime (specified as amounts of water, and their timing, frequency, duration and variability) to sustain the biophysical components, ecological processes and health of aquatic ecosystems, and the ecological goods and services they provide.

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