

Hydromorphology

Richard M. Vogel, Ph.D., M.ASCE

Professor, Dept. of Civil and Environmental Engineering, Tufts Univ., Medford, MA 02155. E-mail: richard.vogel@tufts.edu

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Introduction

Analogous to the field of geomorphology (a subfield of geology that deals with the structure and evolution of the surface of the earth), the new field of hydromorphology (a subfield of hydrology), deals with the structure, evolution, and dynamic morphology of hydrologic systems over time (e.g., years, decades, and centuries). The need for this new subfield of hydrology stems from the enormous societal challenges and demands resulting from a growing human population combined with the pervasive human impacts on environmental and water resource systems. In many regions, the hydrologic cycle has been transformed by human activities that impact water use, land use, and climate at nearly all spatial and temporal scales. Human influences tend to interact and manifest themselves in complex ways, so that it is now difficult to find a watershed subject only to natural or unimpacted hydrologic conditions. Nearly every hydrologic method upon which our profession is based will need to be adapted to account for the increased uncertainty and nonstationarity that have become the central challenge of our profession. The science of hydromorphology involves the development of a conceptual basis for improving our understanding of the impact of humans on the hydrosphere. Hydromorphologic engineering involves the development of methods to detect, attribute, design, manage, and predict water resources in a hydrosphere, which is subject to multiple and interacting sources of uncertainty and nonstationarity.

Introduction to New Field of Hydromorphology

Hydrologic systems evolve because of a variety of both natural and anthropogenic influences such as changes in land and water use caused by urbanization, agriculture, climate change, modifications to water infrastructure and water use, and a variety of other factors. The evolution of a hydrologic system in response to such influences at the scale of years to centuries is called its *hydromorphologic response* (K. Dressler et al., unpublished lecture, 2006).

Hydromorphology Is to Hydrology as Geomorphology Is to Geology

Geology is that branch of science dealing with the study of Earth, the materials of which it is made, the structure of those materials, and the processes upon them.

Hydrology is that branch of science dealing with the study of water on Earth, encompassing its occurrence, distribution, and movement, as well as its relationship to all aspects of the environment it interacts with.

Geomorphology is that subfield of geology that deals with the structure and evolution of the surface of Earth. Geomorphology deals with the origin and dynamic morphology (changing structure and form) of Earth's land surfaces.

By Analogy

Hydromorphology is that subfield of hydrology that deals with the structure and evolution of Earth's water resources. It deals with the origins and dynamic morphology of those water resources. Analogous to geomorphology, which deals with the dynamic morphology of the earth system, hydromorphology addresses the dynamic morphology of water resource systems caused by both natural and anthropogenic influences.

Hydromorphology: Interdisciplinary Field of Science and Engineering

The dynamic morphology of hydrologic systems can be viewed in much the same way one views the dynamic geomorphology of a fluvial system. Fluvial systems evolve because of both natural and anthropogenic influences, as do hydrologic systems. Because fluvial systems are a component of hydrologic systems, hydromorphology encompasses the field of geomorphology. Similarly, because hydromorphology involves a heavy emphasis on improving our understanding of the impact of anthropogenic influences on the hydrosphere, hydromorphology is closely related to numerous social sciences including geography, urban planning, and environmental economics, as well as to all common scientific disciplines that are central to hydrology.

Hydromorphology: Field Looking for Home

The fields of geology and hydrology have existed for centuries and are now rich and fertile fields with both scientific and engineering challenges. Evidence of their health is provided by the more than 41 and 25 million Google search hits for the terms *geology* and *hydrology*, respectively. By comparison, the subfields of geomorphology and hydromorphology are in their infancy, with only 9 and 0.02 million Google hits, respectively. Apparently, the term *hydromorphology* is in search of a field.

Hydromorphology Is Not a New Idea: Why Is It Needed and Why Now?

There are several conflicting definitions of the term *hydromorphology*, yet none of the existing definitions appear to be in widespread usage. Until the turn of the twentieth century, the most widespread use of the term *hydromorphology* was in reference to a classification system for soils (Rabenhorst et al. 1998). Wilding and Lin (2006) and many others refer to the hydromorphologic structure of soil systems. The soil science literature uses the term *hydromorphology* more as a qualifier of the structure of soil systems than as a subfield of soil science.

More recently, Orr et al. (2008) suggest that the definition of the term *hydromorphology* is subject to debate. Orr et al. (2008) define hydromorphology as the physical habitat constituted by the flow regime (hydrology and hydraulics) and the physical template (fluvial geomorphology), which is similar to the definitions introduced by Newson and Large (2006). In other instances, when the term *hydromorphology* is not explicitly defined, its implied meaning involves a blend of hydrology, geomorphology, and ecology (Šípek et al. 2009). According to Laminar, Ltd. (2010) *hydromorphology* is a term that has been created for the European Union Water Framework (it has actually been "appropriated" from soil science) but has been given a new and specific meaning, which is "the

hydrological and geomorphological elements and processes of waterbody systems.” (European Commission 2000).

The definition of hydromorphology introduced here is different from all previous definitions, but it is identical to that originally introduced by Dressler et al., which is perhaps the most general definition to date. Hydromorphology is defined as a subfield of hydrologic engineering and science that deals with problems relating to the structure, evolution, and dynamic morphology of hydrologic systems over time (e.g., years, decades, and centuries). This field arises not from semantic arguments but from the growing need for society to deal more directly with the profound environmental and water resource impacts that are being generated by human development on a global scale.

It is instructive to compare the history of geomorphology with that of hydromorphology. Sack (2002) reviews the history of geomorphology and suggests that the first published use of the term *geomorphology* was by McGee (1888). Yet Sack (2002) and others cite many other geomorphology studies that occurred prior to McGee (1888) but did not use the term *geomorphology* to describe their work. Similarly, there are many previous studies in the field of hydrology and water resources engineering that could be characterized as hydromorphologic studies. For example, any previous study dealing with either anthropogenic or natural influences on the hydrosphere, as well as their interactions and consequences, can now be referred to as hydromorphologic studies. Likewise, studies that seek to improve our ability to plan for nonstationarity, including design, adaptation, and mitigation strategies, would now be called hydromorphologic studies. One of the first steps in solving a problem is always problem identification. In a sense, naming the class of hydromorphologic problems gives attention to the challenges we face and reinforces its relevance and significance.

Hydromorphologic Science and Engineering

Analogous to geomorphology, there are both engineering and scientific challenges associated with hydromorphology. Hydromorphologic scientists will seek to improve our conceptual understanding of the impacts of the multiple interacting and pervasive human and natural influences on the behavior of hydrologic systems. Hydromorphologic engineers will develop improved methods to operate, plan, and manage water resources to accommodate the increased uncertainty and nonstationarity, which result from the multiple interacting and pervasive human and natural influences that have led to ecosystem degradation, biodiversity losses, and global climate change.

Perspective of Hydromorphologic Scientist

Numerous recent studies argue that the hydromorphologic response of watersheds is paramount to hydrologists because of the now pervasive anthropogenic impacts of population growth, urbanization, ecosystem degradation, biodiversity losses, and global climate change (Vörösmarty et al. 2004; Milly et al. 2008; Wagener et al. 2010). Those pervasive human influences make it difficult to find a nonimpacted watershed, yet scientific or research watersheds are still considered as watersheds without human impacts. On the contrary, if one takes a hydromorphologic perspective, scientific or research watersheds exhibit a wide range of anthropogenic influences, ranging from forested and agricultural watersheds to highly urbanized ones and those dominated by water infrastructure. This raises enormous scientific hydromorphologic challenges because watersheds and other water resource models will have to include mathematical/conceptual models of a wide range of human processes in addition to traditional natural hydrologic ones.

At present, most conceptual formulations of human influences such as residential and industrial water use, best management practices, irrigation, and storm-water systems were formulated by engineers and were incorporated in engineering models to enhance the design of infrastructure and operation of water resource systems. Hydromorphologic science will need to respond to challenges that engineering hydrologists faced in the past because their focus will evolve to improving our understanding of the interactions among human and natural processes. The recent studies by Weiskel et al. (2007) and Wang and Cai (2009) are good examples of the type of scientific analyses needed to reformulate basic hydrologic premises, such as the continuity equation and hydrograph recessions, respectively, for hydrologic systems, which are subject to a mixture of natural and anthropogenic influences.

Perspective of Hydromorphologic Engineer

Analogous to the developments in scientific watershed and water resource models described earlier, engineering-oriented water resource models will need to evolve to meet the new and emerging challenges of hydromorphology. Concerns over watershed damages caused by population growth, urbanization, ecosystem degradation, biodiversity losses, and global climate change challenge engineers to develop fully integrated and modular modeling systems. It will no longer be adequate to design water resource infrastructure in isolation, such as an individual culvert, dam, well, or recharge basin. Instead, such infrastructure will be designed by using integrated systems models, so that, for example, flood control and water supply objectives do not compete with one another; instead, a recharge basin may be chosen because it serves to reduce flood flows and increase groundwater supplies while it improves water quality goals and ecosystem services. An example of the future of hydromorphologic engineering is provided by the generalized watershed management modeling systems envisioned by Zoltay et al. (2010), when they attempted to develop an integrated decision support system for selecting the optimal combination of management alternatives from an extremely broad class of land, ground, and surface water; recycling; wastewater; and best management practices.

Conclusions

We have already experienced a major transition in the development, management, and use of water resources on local, regional, and global scales (Vörösmarty et al. 2004; Milly et al. 2008; Wagener et al. 2010). The field of hydromorphology is introduced to respond to the myriad of scientific and engineering challenges created by the wide range of natural and anthropogenic influences that have literally “morphed” the hydrologic cycle at all spatial and temporal scales. Today’s population of approximately 6.8 billion is expected to increase to 9 billion in the next 40 years. The additional 2.2 billion people will lead to increased water resource system stresses, and the field of hydromorphology is likely to play a central role in seeking to reduce such stresses.

Hydrologic scientists and engineers have always been concerned with planning under nonstationary and uncertain conditions. However, anthropogenic modifications to the hydrosphere are now so profound and pervasive that one of the central challenges facing hydrologists is managing water resources in an uncertain and nonstationary environment while effectively responding to ecosystem degradation, biodiversity losses, and global climate change. Over a quarter century ago, Matalas et al. (1982) called to replace hydrology’s traditional paradigm that largely ignores interactions between human and natural systems with an active paradigm that accepts

anthropogenic impacts on the hydrosphere as being both integral and inseparable within the context of the hydrologic cycle. It is my hope that by naming this new discipline, hydromorphology, engineers and scientists will rise to the myriad of challenges that society faces with respect to global change.

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