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Structure, connections, and dynamics of hydrologic systems: A complex networks perspective

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Hydrologic systems are often made up of a large number of interconnected components. The connections among the components change both in space and in time in highly nonlinear ways. Identification of the structure and connections among the components and understanding of their spatial and temporal evolution have been among the most fundamental challenges in hydrology.

Over the past century, numerous scientific concepts and mathematical methods have been developed and applied for studying the structure, connections, and dynamics of hydrologic systems. Despite the progress, our knowledge about hydrologic systems and their functions remains inadequate. A key reason for this is the absence of a strong scientific theory that is suitable for studying all types of connections encountered in hydrologic systems. This deficiency has increasingly been recognized in recent years, with many calls for development of a generic theory or framework in hydrology. The issue is becoming more important and urgent now, especially with the many new challenges we face, including climate change impacts on hydrologic extremes, water security, and human-water interactions.

Recent developments in the field of complex systems science provide new avenues to address this issue. In particular, the science of complex networks are useful for studying all types of connections in large, complex, and dynamically-evolving systems, such as hydrologic systems. Applications of the concepts of complex networks in hydrology have started recently, and research in this area is just emerging. Thus far, studies have investigated connections in rainfall monitoring networks, streamflow monitoring networks, and river networks, among others. The outcomes of these studies, despite their largely preliminary nature, are certainly encouraging.

This study is intended to discuss the role and future of the science of complex networks in hydrology. Some key concepts of complex networks and their relevance to hydrologic systems are reviewed. Examples of applications of such concepts for studying various connections in hydrology are presented, including those associated with studies on rainfall, streamflow, water quality, catchment classification, and optimal monitoring networks. These lead to some specific directions the science of complex networks can assume in hydrology in the future, especially in the context of grand challenges in hydrology.