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Constructing Comprehensive Datasets for Understanding Human and Climate Change Impacts on Hydrologic Cycle

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Background

Climate change and human activities altered the hydrologic systems and exerted global scale impacts on our environment with significant implications for water resources [1]. To secure a complete picture of future water resources, it will be necessary to consider climate change and variability, hydrology, water engineering, and human systems in an integrated framework [2]. Climate change can be characterized by the change of precipitation and temperature, and both precipitation pattern change and global warming are associated with the increase in frequency of flooding or drought and the decrease of low flows. With increasing water demand from domestic, agricultural, commercial, and industrial sectors, humans are increasingly becoming a significant component of the hydrologic cycle. Human activities have transformed hydrologic processes at spatial scales ranging from local to global as shown in figure 1. Human activities affecting watershed hydrology include land use change, dam construction and reservoir operation, groundwater pumping, surface water withdrawal, irrigation, return flow, and others e.g., Wang and Cai [3], Vogel [4]. The land use change impacts have been studied in many watersheds around the world. However, the fundamental role of human water use in the hydrologic cycle is not yet well understood [5].

Although the importance of human impact on the streamflow is becoming recognized, there remains a critical need to quantify the human interferences to hydrologic systems at various temporal and spatial scales. It is a challenge to separate and quantify the contribution of human and climate change to hydrologic changes at various temporal scales. At the mean annual scale, it was found that climate change causes increased streamflow in most watersheds while the direct human-induced change is spatially heterogeneous in the continental United States, with strong regional patterns, e.g., human activities causing increased streamflow in the Midwest and significantly decreased steamflow in the High Plains [6]. At event scale, the long-term trends of baseflow recession slope in agricultural and urban watersheds in Illinois are primarily induced by human interferences such as irrigation and effluent discharges [7].

The evolution of hydrologic systems in a changing environment can be understood from a retrospective view based on historical records. New theories can be developed for the co-evolution of coupled human and water systems and utilized for projecting the future water resources availability under climate change/variability and human development. However, currently, data availability of human activities is limited and water use data (including domestic, industrial sectors, and irrigated agriculture) involve considerable uncertainties [5], which challenges the effectiveness of incorporating direct human interferences into hydrologic modeling. Natural hydrologic processes have been measured and simulated sophisticatedly by detailed models at different time and spatial scales, but data about the human aspects of water uses are not easily available [8]. As a result, hydrological observatory networks at the river basin scale are suggested to more closely monitor human impacts across multiple scales. The proposed observatory-related initiatives, such as Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) and Collaborative Large-Scale Engineering Analysis Network for Environmental Research (CLEANER), aim to, but are not limited to, data availability problem, especially for the human side [9].

Data on Human Activities

The data of direct human interferences such as irrigation, groundwater pumping, return flow, and reservoir operation at catchment scales, as well as the land use change specifically urbanization, are suggested to be collected and constructed.

Globally two-thirds of water withdrawals are used for irrigation and irrigation sector accounts for 90% of water consumption [10]. The direct impact of water withdrawal for irrigation, such as groundwater and streamflow depletion, has been studied since 1990s [11]. However, irrigation inputs are usually ignored in catchment hydrology and land atmosphere interaction, particularly because irrigation water use data are difficult to obtain. In practices, the rule-based irrigation input (when and how much to irrigate) scheme is usually determined internally by models with specified empirical criteria, or prescribed as an external model input, but farmers may not behavior like that in reality. Without an accurate estimation of such direct human interferences, it is difficult to judge if the model outputs are correct. Therefore, finding reliable quantification of human inputs, which may be time dependent and unknown, or handling the errors involved in existing human activities data is important to simulate hydrologic processes that are heavily affected by irrigation practices.

Water uses connect human and hydrologic systems. Water withdrawal from surface water or groundwater is a major form of direct human interferences on the hydrologic cycle in many river basins, which can be revealed by historical streamflow record versus water use record. If water withdrawal and return flow is non-negligible, hydrologic simulation model should take it into account at both calibration and prediction stages [12,13]. Without a detailed accounting of the water withdrawal, the water balance accounting would be invalid. For example, [14] showed that not accounting for diversions by groundwater pumping would overestimate evapotranspiration in both magnitude and trend.

A single large dam or multi-reservoir systems are built to meet the human needs, such as generating electricity, water supply, flood control, and recreation. In a catchment with multi-reservoirs, the streamflow can be controlled by reservoir operation rules [15,16]

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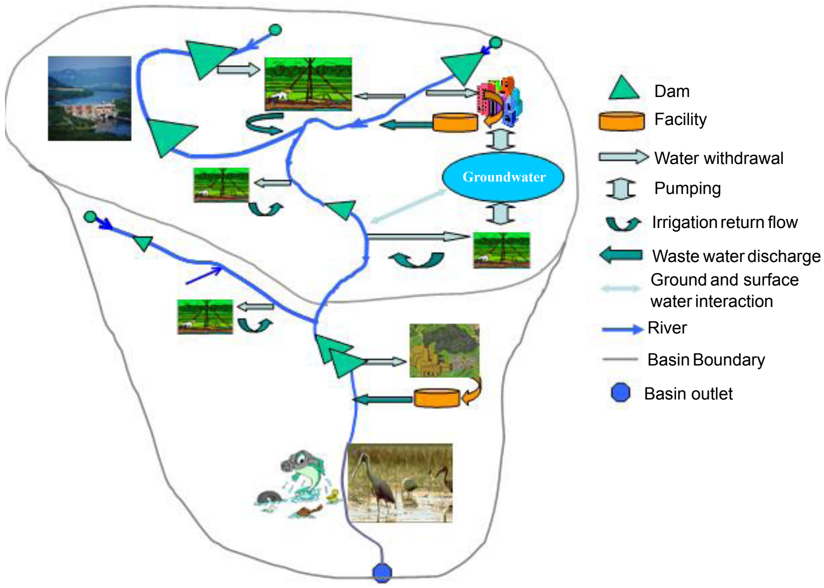

Figure 1: Coupled human and hydrologic systems in catchment scale.

analyzed the long-term monthly discharge records in Lena River watershed and found that reservoir regulations have significantly altered the monthly discharge regime in the lower parts of the basin, for example, high flow reduced by 55% and low flow increased by 30 times. Since reservoir operation changes the flow regime considerably, the calibration of a hydrologic model and the prediction of streamflow without considering this human regulation will not be realistic. The combination of hydrologic simulation model and reservoir operation model is necessary for streams with major dams. But only a few studies considered the streamflow regulation and water withdrawal in hydrologic simulation model [17,18]. Moreover, the operations are unknown or uncertain, because the real operation rules may be different from what were prescribed. This usually causes the difficulty to include reservoir operations in a hydrologic simulation model.

Land use practices are an important factor of global climate through the carbon cycle and also affect regional climates through the changes of surface energy and water balance [19]. Since the 1960's, the effects of land use change and urbanization on watershed hydrology have been extensively studied [20]. The impacts of land use change include, but not limited to, the surface runoff, evapotranspiration, and groundwater recharge [21]. For example, Zhang and Schilling [22] found that the conversion of perennial vegetation to seasonal row crops is the main reason of increased streamflow in the Mississippi River since the 1940's. The role of land cover should be explicitly accounted in a hydrology model in order to separate the impact of land use and climate variation and change [23]. In an urban watershed, the main land use change includes the increase of impervious area, and the estimation of effective impervious area is important to correctly quantify the runoff. The land use change is may be stable in a short-term period but variant in a long-term period.

Summary

The existing datasets usually do not include watersheds with significant human activities because hydrologic research has been focused on developing theories for natural watersheds. Therefore, it is imperative to develop comprehensive datasets for watersheds with extensive human inferences in order to quantify and understand human impacts on the hydrologic cycle. Through these datasets, research on watersheds with extensive human activities can be conducted to improve our understanding of the role played by human in the coupled human and water systems. The purpose of this editorial is to call for efforts to collect and assemble a comprehensive dataset with human activities and hydrologic variables at watersheds under different conditions of climate, vegetation, topography, soil properties, and human development.

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