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Integrated Water Resources Research: Advancements in Understanding to Improve Future Sustainability

Jason A. Hubbart
West Virginia University

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Editorial

Integrated Water Resources Research: Advancements in Understanding to Improve Future Sustainability

Jason A. Hubbart [1,2,3]

[1] Institute of Water Security and Science, West Virginia University, 3109 Agricultural Sciences Building, Morgantown, WV 26506, USA; jason.hubbart@mail.wvu.edu; Tel.: +1-30-4293-2472
[2] Division of Plant and Soil Sciences, Davis College of Agriculture, Natural Resources and Design, West Virginia University, Agricultural Sciences Building, Morgantown, WV 26506, USA
[3] Division of Forestry and Natural Resources, Davis College of Agriculture, Natural Resources and Design, West Virginia University, Agricultural Sciences Building, Morgantown, WV 26506, USA

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Abstract: Anthropogenic and natural disturbances to freshwater quantity and quality is a greater issue for society than ever before. To successfully restore water resources in impaired watersheds requires understanding the interactions between hydrology, climate, land use, water quality, ecology, social and economic pressures. Current understanding of these interactions is limited primarily by a lack of innovation, investment, and interdisciplinary collaboration. This Special Issue of Water includes 18 articles broadly addressing investigative areas related to experimental study designs and modeling (n = 8), freshwater pollutants of concern (n = 7), and human dimensions of water use and management (n = 3). Results demonstrate the immense, globally transferable value of the experimental watershed approach, the relevance and critical importance of current integrated studies of pollutants of concern, and the imperative to include human sociological and economic processes in water resources investigations. Study results encourage cooperation, trust and innovation, between watershed stakeholders to reach common goals to improve and sustain the resource. The publications in this Special Issue are substantial; however, managers remain insufficiently informed to make best water resource decisions amidst combined influences of land use change, rapid ongoing human population growth, and changing environmental conditions. There is thus, a persistent need for further advancements in integrated and interdisciplinary research to improve scientific understanding, management and future sustainability of water resources.

Keywords: watershed management; water quality; water resources; human dimensions of water; watershed modeling; hydrological modeling; water pollutants

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1. Introduction

The requirements to understand, synthesize, and resolve water resource challenges are more complex today than any time in human history. The scope of contemporary water resource challenges requires an unprecedented amount of information that spans a continuum of physical, natural and socioeconomic sciences [1]. For the first time in history, a freshwater crisis has grown global in proportion. This is at least in part attributable to economic globalization and continuing human-induced perturbation of natural resource commodities including the water cycle. This crisis is manifested in many sectors including (but not limited to) politics, public health, agriculture, development and the environment [2]. In the United States alone, unwavering aggressive use of freshwater resources, leading to scarcity and quality problems, requires innovative, interdisciplinary and integrated scientific, technological, and training solutions. This perspective is important given that cumulative anthropogenic drivers (e.g., land use, population growth, climate change) confound the uncertainties of decision-making, and many critical information gaps remain. Such cumulative alterations impact water quality (e.g., chemical composition, pathogen presence and persistence) and quantity (e.g., low flows, peak flows, flooding) regimes [3–6], and can ultimately result in further freshwater ecosystem degradation. Land managers are thus often inadequately informed to make correct management decisions in regions where sources of impairment are simultaneously shifting due to combined influences of land use change, rapid ongoing human population growth, and changing environmental conditions. Given the inherent complexity of these dynamic systems, it is not surprising that effective management is dynamic, characterized by ongoing scientific advancements and policy refinements [7,8]. The intent of this Special Issue of Water was to provide some of the latest integrated and multidisciplinary water resources research that advances the understanding, sustainability and therefore management of water resources.

2. Special Issue Overview

This Special Issue of Water entitled, "Integrated Water Resources Research: Advancements in Understanding to Improve Future Sustainability" includes 18 articles broadly addressing investigative areas related to experimental study designs and modeling (n = 8), fresh water pollutants of concern (n = 7), and human dimensions of water use and management (n = 3), presented, in brief, in the following text.

2.1. Experimental Study Designs and Modeling

A case study was presented by Hubbart et al. [9] using an experimental watershed study design and collaborative adaptive management (CAM) framework [1] to illustrate how these approaches can be used in mixed-land-use (including municipal) watersheds to provide quantitative information to identify and address past, present, and future sources of impairment, and thus better utilize limited taxpayer funds towards mitigation. Results identified challenges associated with CAM, and how the experimental watershed approach can help to objectively elucidate causal factors, target critical source areas, and provide the science-based information needed to make informed management decisions. Results further demonstrate the immense, globally transferrable value of the experimental watershed approach for municipal watersheds. Mixed land use influences on stream physical habitat was investigated by Zeiger and Hubbart [10] who directly measured channel geomorphology, and stream substrate composition every 100 m over 56 km (n = 561). Results showed that agricultural and urban land use explained nearly all the variance in average river width to depth ratios (R^2 = 0.960; p = 0.020; n = 5), and maximum bank angle (R^2 = 0.896; p = 0.052; n = 5). Streambed substrate samples indicated significantly ($p < 0.001$) increased embeddedness at agricultural and urban sites. Results demonstrate how hydrogeomorphological assessments can help guide regional stream restoration efforts. Cao et al. [11] used a three-stage data envelopment analysis (DEA) model and Chinese provincial panel data to analyze input efficiency of water-saving irrigation. Results showed that overall efficiency of water-saving irrigation practices are increasing nationally (China). Authors noted that efficiency of water-saving irrigation input will significantly increase investment in areas such as Hainan, Chongqing, Guizhou, Tibet, and Qinghai. Kutta and Hubbart [12] investigated land cover alteration (e.g., reforestation) feedbacks on climate with respect to implications for ecology, water resources, and watershed management. Results indicated an increasingly wet and temperate climate for the Northeast United States, and specifically the state of West Virginia, characterized by warming summertime minimum temperatures, cooling maximum temperatures, and increased annual precipitation that accelerated during the second half of the period of record (1959–2016). Trends were elevation dependent and may be accelerating due to local to regional ecohydrological feedbacks including increasing forest age and density, changing forest species composition, and increasing globally averaged atmospheric moisture. Importantly, results imply that excessive wetness may become the primary ecosystem stressor associated with climate change in the USA's rugged and flood prone Appalachian region and by extension, similar physiographic regions, globally. Work by Gaertner et al. [13] supported these findings using historic and future predicted climate and water balance data to quantify streamflow sensitivity and project future streamflow changes for 29 forested catchments in the Northeast United States. Results showed that streamflow is expected to increase under the low-emission and decrease under the high-emission climate change pathway. In related work, Rojano et al. [14] showed that modeled urban flow regimes were correlated to net ecosystem production (NEP), and under hypoxic conditions, local inflows were correlated with specific conductance. Results show the value of using integrated modeling approaches with observed data to resolve big-river challenges. El Hafyani et al. [15] developed a method to assess regional water balances using remote sensing techniques in the Boufakrane river watershed in Meknes Region (Morocco). Using a supervised classification procedure and combined mapping procedure, the water balance was developed considering changing management and consumption patterns. Results showed that urban areas, natural vegetation, arboriculture and cereals increased the water balance by approximately 184%, 13%, 35% and 49%, respectively, while forests and bare soils decreased the water balance by approximately 79% and 17%, respectively. Further, increased water consumption by human activities was largely mitigated by evapotranspiration savings from deforestation, a practice that can no longer be sustained. Finally, Gootman et al. [16] conducted a study validating five saturated hydraulic conductivity (K_{sat}) pedotransfer functions in a catchment of the Chesapeake Bay Watershed, Northeast United States. The study showed that dry bulk density and porosity were significantly different by location ($p < 0.05$) and four different models corroborated that spatial variability in farm-scale K_{sat} estimates was small (CV < 0.5), thereby validating the use of simple, soil-property-based models to predict K_{sat}, thereby increasing model applicability and transferability. These investigations advance understanding of land use and modeling practices on water resources and therefore predictive confidence in water resources management decisions.

2.2. *Fresh Water Pollutants of Concern*

Multiple articles were published that quantitatively characterize relationships between Escherichia (E) coli concentration, suspended particulate matter (SPM) particle size class, physicochemical concentrations and land use practices. These articles are some of the first (globally) that use the study design described in Hubbart et al. [1,9] to advance aquatic microbial process understanding. For example, Petersen and Hubbart [17] showed that statistically significant relationships exist between E. coli concentration, size interval ($p < 0.0001$) and suspended particulate matter (SPM) ($p = 0.05$). Results showed a predominance (90% of total) of E. coli colony forming units (CFU) in the <5 µm SPM interval. Petersen and Hubbart [18] showed that Annual average E. coli concentration increased by approximately 112% from acid mine drainage (AMD) impacted headwaters to lower watershed reaches (approximate averages of 177 CFU per 100 mL vs. 376 CFU per 100 mL, respectively). Significant Spearman's correlations ($p < 0.05$) were identified from analyses of pH and E. coli concentration data representing 77% of sample sites. Results highlight legacy effects of historic coal mining drainage on microbial CFUs in fresh water. A tipping point of 25–30% mixed development was identified as leading to significant ($p < 0.05$) negative correlations between chloride and E. coli concentrations. Agricultural land use sub-catchments were shown to have elevated E. coli concentrations (avg. 560 CFU per 100 mL) relative to proximate mixed development (avg. 330 CFU per 100 mL) and forested (avg. 206 CFU per 100 mL) sub-catchments [19]. Additionally, agricultural land use showed statistically significant relationships ($p < 0.01$) between annual E. coli and SPM concentration. Quarterly principle component analysis (PCA) biplots indicated temporal variability in land use impacts on E. coli and SPM concentrations, with agricultural land use being closely correlated with both pollutants during spring and summer quarters but not fall and winter quarters. Finally, Petersen and Hubbart [20] provided an overview of factors known to impact the survival of E. coli in the environment. Findings indicated (1) large knowledge gaps regarding environmental factors influencing E. coli's survival in the environment, and (2) a lack of implemented management strategies assessed at larger field scales, thus leaving their actual impact(s) largely unknown. Kessler et al. [21] used an in silico ontological pathway analysis to identify the genes affected by the most commonly detected endocrine-disrupting chemicals (EDC) in large river water supplies, grouped by organismal injuries, cell death, cancer, and behavior. Results highlighted the critical need of additional investigations with a potential emphasis on the effects linked to increased DNA impacts. Spatio-temporal variability in total dissolved solids (TDS) was investigated using a modeling approach within a large river basin of the Northeastern United States to assess the extent and drivers of vulnerability to TDS exceedance [22]. It was shown that consistently low TDS from contributing surface waters to receiving water reduced vulnerability to elevated TDS. Authors identified that management should include efforts to increase assimilative capacity and manage upstream reservoirs. Finally, Horne and Hubbart [23] used the design explicated by Hubbart et al. [1,9] and Petersen and Hubbart [17–19] to investigate stream water temperature (Tw) and land use practices. Using data from 21 stream temperature monitoring sites, results showed that forested land use was negatively correlated ($p = 0.05$) with mean and maximum Tw and agricultural land use was significantly positively correlated ($p = 0.05$) to maximum Tw. Mixed development and Tw were also shown to be significantly correlated ($p = 0.05$) depending on time of year. Correlation trends in some reaches were reversed between the winter and summer seasons, contradicting previous research. Independently, and collectively, these studies advance understanding of land use impacts on many water quality constituents of concern, and aid in the decision making of effective water quality management practices and policies.

2.3. Human Dimensions of Water Use and Management

Under the research theme of resilience by means of service and rapid recovery after disasters it was shown that sufficient technology and good water quality are not enough for achieving resilient water services, but education and institutional management are essential components of that process that can be achieved by a deliberate education system, capacity building, and good governance [24]. Spatial patterns of water quality perceptions were gathered in a survey of southwest West Virginia (WV), United States residents to identify significant differences across counties labeled as socioeconomically transitional, at-risk, and distressed, relative to water quality perceptions, education level, and income level [25]. Findings highlighted the importance of location on water quality perceptions and presented an analytical framework that could be applied to future research. Finally, a study performed in Tanzania showed quantitative relationships between increasing population food insecurity and climate change relationships related to small farm landowners ($n = 701$) standards of living [26]. A bivariate logistic regression model was developed to relate application of water conservation techniques (WCT) to household socio-economic, and farmer perception related variables. Results, suggest that policies must encourage conservation behavior, emphasize the economic and food security-related benefits of adopting WCTs, include strategies that make adoption of WCTs attractive, attempt to reach greater number of farmers via social networks and provide better access to public funds.

3. Conclusions

Published articles from this Special Issue of Water address many aspects of integrated and multidisciplinary water resources research. Article contributions include advancements in effective ways of conducting integrated water research and communicating results to promote deliberate advancements in management, human well-being, and resource sustainability. Assuming human-induced environmental changes continue as anticipated, there is a need for highly organized efforts to continuously monitor, model and improve best management practice decisions to mitigate anthropogenic and natural pressures on water resources. This pursuit is critical because, in the absence of advances in integrated and interdisciplinary observed data and modeling, sources of impairment may remain unrecognized and unaddressed.

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