INTRODUCTION: ENHANCING THE CAPACITY FOR SUSTAINABLE WATERSHED MANAGEMENT

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Watersheds constitute the lifeblood of human civilization and environmental systems – they support a diverse array of ecosystem components, as well as providing a precious source of freshwater supply, both surface water and ground water. However, watershed resources are being increasingly polluted and depleted due to population pressures and economic activities. This may lead to a decline in living standards and adversely affect ecological integrity (Arrow *et al.,* 2004). Two-hundred of the world's leading scientists from more than 50 countries recently ranked issues related to sustainable watershed management among the most urgent environmental priorities (Brooks, 2003). Sustainable watersheds are those managed to meet socio-economic goals and objectives for current and future generations, while maintaining their ecological and hydrological integrity (ASCE, 1998; UNESCO, 1999). Accordingly, sustainable watershed management involves value laden multicriteria tradeoffs in a multidisciplinary and multistakeholder decision making process. Humanity currently stands at a "watershed" moment concerning the sustainable management of our environmental systems. Preparing for the impending shift to a sustainable future requires an enhanced capacity for sustainable watershed problem solving, by utilizing both market institutions and a transformational, participatory approach to community decision making.

Despite several decades of intensive research, sustainable watershed management issues continue to be in the vanguard of studies for robust, integrated, and adaptive environmental planning. Watershed sustainability is inhibited by a number of factors. First, environmental laws and regulations often work at cross purposes. Second, incentives and policies too often emphasize technical and biophysical watershed aspects without integrating financial and social issues. Finally, devolution of responsibility for watershed planning to local agencies has occurred without the requisite financial, scientific, and human resources. Given the vital importance of sustainable watershed planning and management, the American Water Resources Association (AWRA) sponsored a Summer Specialty Conference in June 2005 in Honolulu, Hawaii, entitled Institutions for Sustainable Watershed Management in the Asia-Pacific: Reconciling Political and Management Ecology. The papers in this Featured Collection derive from this conference, and address a number of important questions regarding sustainable watershed theory and practice. What are the best financial and ecological management practices to protect and restore watersheds, including surface and ground water? How best can we integrate values, ethics, and engineering technology to address water quality and supply concerns? How can we deal with overlapping jurisdictional boundaries to improve the welfare of riparian communities and promote watershed conservation?

The nine papers found herein demonstrate that restoring, preserving, and protecting watersheds goes beyond technology-based solutions. For example, economic and regulatory contributions include financial arrangements for water resources projects, environmental rules and regulations, water rights, participatory conflict resolution, and pricing incentives. Ecological engineering designs for sustainable watershed management include stormwater best management practices (such as wet detention ponds/basins,

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bioretention wetlands, and bioswales), groundwater recharge facilities, and stream restoration projects.

Three papers deal with economic policies and financial arrangements for sustainable watershed management. Pitafi and Roumasset (2006) estimate and compare welfare gains from pricing reform and watershed conservation. They show that pricing reform is welfare superior to watershed conservation unless the latter is able to prevent very large recharge losses. Levy *et al.* (2006) propose bioeconomic models in order to improve the accuracy and reliability of maximum sustainable yield fisheries management. Stochastic population models are used to analyze the risk of a fish stock collapse due to harvesting pressures. Ringler *et al.* (2006) discuss an integrated economic hydrologic approach to water allocation policies for the Dong Nai River Basin in southern Vietnam. Their model takes into account the sectoral structure of water users (agriculture, industry, hydropower, households, and the environment) and develops water benefit functions for major water uses subject to physical, system control, and policy constraints.

Four papers deal with watershed quality problems caused by intensification of agricultural and animal production systems. A major threat to watersheds comes from the use of fertilizer, pesticides, herbicides and other chemicals in our rivers, lakes, reservoirs, and coastal waters. Schuck *et al.* (2006) discuss the importance of institutional structure in controlling water quality problems related to agricultural runoff in Colorado and California. They show that while both states face similar water quality challenges, the ability to manage these problems and the types of policy tools available to manage them differ greatly. The choice of institutional arrangements profoundly affects on-farm incentives for reducing agricultural runoff, which in turn translates into different policy choices to manage this runoff.

Kanwar (2006) discusses the impact of landscape activities on water pollution and hypoxia. To help reduce the transport of nutrients from agricultural watersheds long term studies were carried out, and the impact of tillage, crop rotation, and N-management practices on NO_3-N leaching losses to subsurface water resources were investigated. Specifically, NO_3-N leaching losses are found to be higher in continuous corn than in rotated corn in plots fertilized with either manure or urea ammonium nitrate. The higher N application rates from swine manure resulted in higher NO_3-N concentrations in the subsurface drainage tile water.

Johnson and Gerald (2006) note that the control of excess nutrients from nonpoint source pollution is difficult because the source areas can be hard to identify and the pollutants are distributed over a wide area. Best management practices are put forth to reduce nutrient related water quality problems. Their physically based watershed assessment and management models include important processes that generate stream flow and material transport, uptake, loss, transformation, and recycling of nutrients/material. The authors emphasize that while agricultural restoration attempts may provide significant benefits, they can be costly to implement and often are met with resistance in agricultural communities.

Fares *et al.* (2006) put forth advances in soil water monitoring in order to improve the efficiency of agricultural water resources management. They discuss the use Multisensor Capacitance Probes for the real-time monitoring of soil water content at multiple depths and various locations. Specifically, the authors investigate the effect of water content on the soil bulk density of Wahiawa silty clay tropical soil in Hawaii and measure the saturated hydraulic conductivity of this tropical soil in the field. In addition, a calibrated Multisensor Capacitance Probe system is used to monitor and evaluate real-time soil water content variations in a tomato crop. Both water inputs (irrigation and rainfall) and outputs (evapotranspiration and deep percolations) contribute to significant variations in soil water content within the rootzone. Finally, results show that water content variations in the soil layer below the rootzone were substantially less than variations within the rootzone.

The two final papers of this special issue deal with geochemical transport modeling and flood modeling. Šimůnek *et al.* (2006) use the HYDRUS-1D software package to improve multicomponent geochemical transport modeling. An important contribution involves the development of two coupled geochemical models based on the HYDRUS-1D software package for variably saturated flow and transport. It is shown that the transport of reactive contaminants in the subsurface is generally affected by a large number of nonlinear and often interactive physical, chemical and biological processes.

Their work enables quantitative predictions for important water resources problems such as analyzing the effects of salinity on plant growth and the leaching of toxic trace elements.

Shiau *et al.* (2006) present a methodology for bivariate frequency analysis of flood peak and volume. Copulas are used to model the dependence between flood peak and volume and to link the pre-determined univariate marginal distributions of flood peak and volume to construct bivariate flood distributions. The annual Jhuoshuei River floods in Taiwan illustrate the proposed methodology. The derived bivariate frequency of floods offers improved understanding of the flood process and useful information in preparing flood mitigation measures.

The papers published in this Featured Collection and presented at the conference in June 2005 demonstrate the quality, breadth and depth of planning and management approaches to sustainable watershed management. A unifying theme is the effectiveness of decision making and problem solving to improve the long term integrity of water resources systems and human well being. Several papers challenge conventional paradigms for watershed management while others provide new insights into the hydrologic and hydraulic sciences. Some studies looked exclusively at ground water systems while others considered ground water-surface water interactions and the relationship between human activities and environmental impacts. Integrating science and policy requires not only an understanding of watershed boundaries, rainfall-runoff characteristics, and other physical properties, but also an appreciation of water rights and the role of water resources institutions, policies, and regulations. The challenge for water resources managers, practitioners, and academics is to enhance the sustainable watershed approach by empowering stakeholders and combining the expertise of scientists from various disciplines. The results described in the nine papers of this Featured Collection provide an important foundation for participatory and adaptive sustainable watershed management.

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