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Introduction to special section on Impacts of Land Use Change on Water Resources

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[1] Changes in land use have potentially large impacts on water resources, yet quantifying these impacts remains among the more challenging problems in hydrology. Water, food, energy, and climate are linked through complex webs of direct and indirect effects and feedbacks. Land use is undergoing major changes due not only to pressures for more efficient food, feed, and fiber production to support growing populations but also due to policy shifts that are creating markets for biofuel and agricultural carbon sequestration. Hydrologic systems embody flows of water, solutes, sediments, and energy that vary even in the absence of human activity. Understanding land use impacts thus necessitates integrated scientific approaches. Field measurements, remote sensing, and modeling studies are shedding new light on the modes and mechanisms by which land use changes impact water resources. Such studies can help deconflate the interconnected influences of human actions and natural variations on the quantity and quality of soil water, surface water, and groundwater, past, present, and future.

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1. Introduction

[2] Given that land use impacts on carbon budgets have been studied for decades [e.g., *Lieth and Whittaker*, 1975; *Vitousek et al.*, 1986; *Haberl et al.*, 2007], surprisingly large uncertainties bracket even the direct effects of land use changes on water resources [e.g., *National Research Council* (NRC), 2006, p. 25]. Irrigated agriculture consumes up to 90% of the world's fresh water supplies [*Shiklomanov*, 2000], with estimated amounts highly sensitive to land use [*Wisser et al.*, 2008].

[3] It is now recognized that land use changes have substantial effects on key atmospheric elements of the hydrologic cycle, including evapotranspiration, precipitation, and land-surface temperatures [*Kabat et al.*, 2004; *Feddema et al.*, 2005; *Juang et al.*, 2007, *Kueppers et al.*, 2007]. Insofar as widespread land use changes can strongly modify regional weather patterns, projections of future changes in the inseparable realms of climate and water resources must consider land use as an important factor [*Foley et al.*, 2005; *NRC*, 2005; *Pielke*, 2008].

[4] Widespread declines in water levels have occurred in critical aquifer systems, including the High Plains of the United States [*McGuire*, 2007], the Murray-Darling Basin of southeastern Australia [*Commonwealth Scientific and Industrial Research Organisation*, 2008], and the Wailapally area of India [*Reddy et al.*, 2009]. Overdrafting of groundwater resources is a growing problem throughout the world [*Konikow and Kendy*, 2005], yet the underlying mechanisms of groundwater supply over broad areas, such as release of water from storage [*Konikow and Neuzil*, 2007] and recharge through deep unsaturated zones [*Scanlon et al.*, 2006; *Stonestrom et al.*, 2007], have only recently been examined.

[5] Land use changes can affect water quality, for example, by introduction of nitrogen compounds and other biologically active solutes [e.g., *Schlesinger et al.*, 2006; *Schlesinger*, 2009]. Land use changes can also affect water quality by large-scale alteration of sediment budgets [*Hassan et al.*, 2008; *Valentin et al.*, 2008]. Additional water quality impacts of land use change include salinization of soil water, groundwater, and surface water [*Allison et al.*, 1990; *Schoups et al.*, 2005].

[6] Land-use impacts are not limited to irrigated areas. Dryland agriculture can have large effects on water resources, increasing recharge and flushing accumulated salts to rivers [*Cook et al.*, 2001; *Scanlon et al.*, 2005]. Impacts from dryland agricultural areas, which currently produce about 60% of the world's food supply, are likely to increase as (1) irrigation becomes increasingly constrained by water availability, (2) newly developed dryland cultivars replace their less drought tolerant counterparts, and (3) dryland production of biofuels and replanting of formerly irrigated land for carbon sequestration both undergo expansion [*NRC*, 1996; 2008]. Urbanization affects water resources locally, impacting water quality [*Randhir*, 2003; *Sickman et al.*, 2007], storm discharge [*Hollis*, 1975], and groundwater recharge [*Ku and Simmons*, 1985; *Filippone and Leake*, 2005].

2. Challenges, Approaches, and Progress

[7] Isolating the impacts of land use change on water resources is problematic. Reasons for the difficulty include the wide range in time scales over which impacts from land

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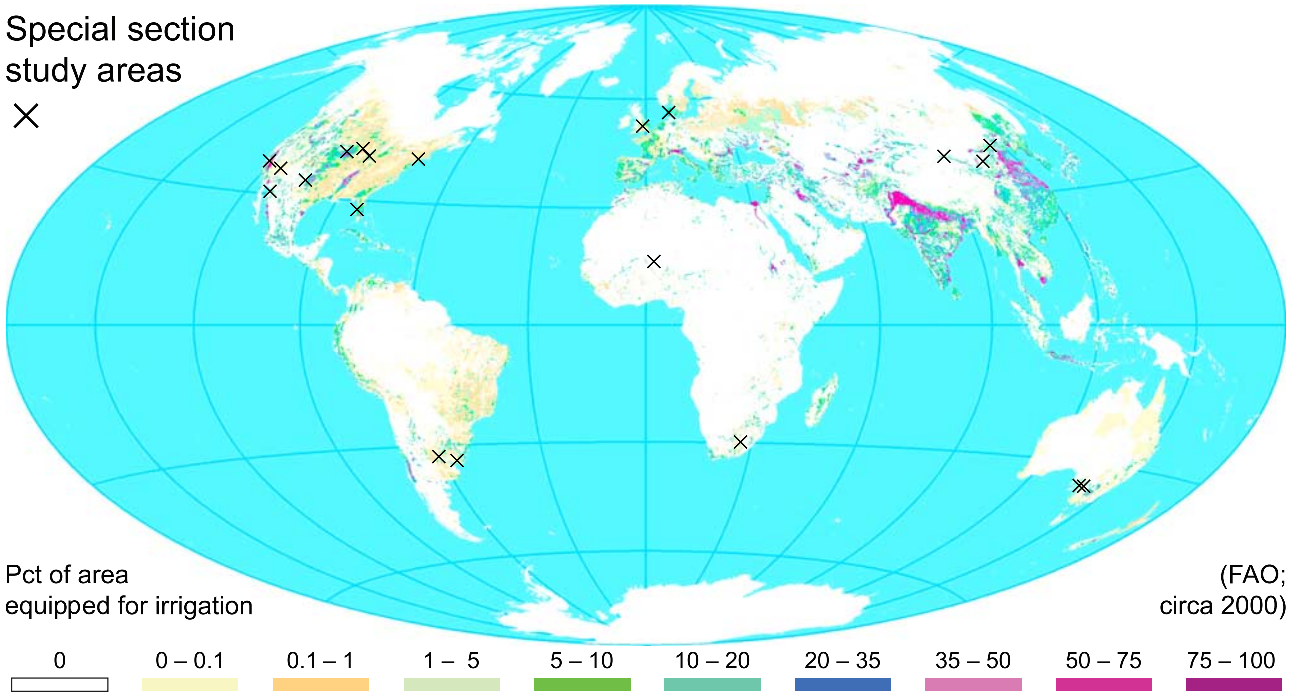

Figure 1. Locations of study areas where land use change impacts on water resources were considered. Base map shows areas reported to be equipped for irrigation roughly as of 2000 (Food and Agriculture Organization of the United Nations data, circa 2000 [*Siebert et al.*, 2005, 2007]).

use changes propagate through hydrologic systems, the confounding effects of climate and weather, and the fact that large-scale observational field studies often lack controls, making it difficult to ascribe temporal changes to causal mechanisms. Biophysical responses such as changes in evapotranspiration occur over time scales of minutes to hours, whereas plant growth and species succession occur over days to decades. Large groundwater systems respond to perturbations in land use and climate more slowly. Studies using stable isotopes and other tracers from unsaturated-zone profiles have shown that groundwater systems in arid regions are still responding to climatic shifts that occurred at the end of the Pleistocene [*Walvoord et al.*, 2004].

[8] The studies presented in this special section apply a variety of observational, modeling, and conceptual techniques to evaluate water resource impacts of land use change at sites located on six continents (Figures 1 and 2). Several studies combine vegetation and water balance models to simulate watershed dynamics for past and projected climates and land use scenarios. Other studies examine specific linkages, such as sulfur dynamics in viticultural systems and changes in soil and stream chemistry due to afforestation. The largest cluster of studies considers watershed dynamics (streamflow and sediment transport) in portions of northern China that have experienced large changes in land use, together with periods of severe drought. Such studies help explain the mechanisms and interactions that led to increasingly frequent zero-flow conditions along the Yellow River during the latter half of the twentieth century. Several studies are global in scope, for example developing models that can help manage "green water" (plant-transpirable water) in addition to "blue water" (surface water and groundwater) to meet increasingly pressing demands and constraints [cf. *Smil*, 2008].

Land Use Changes	Impacts	Approaches (Models)
To irrigated agric.	SM quantity	UZ geochemistry (PHREEQC)
To dryland agric.	SM quality	Biogeochemical (NLOSS)
To tree plantations	SW quantity	GW flow (MODFLOW)
To biofuels	SW quality	SW flow (DTVGM)
To urban/industrial uses	Sed. transport	Watershed (MIKE-SHE; SWAT)
	GW quantity	Green-blue apprortioning (LPJmL)
To conservation	GW quality	Climate (HadCM2, HIRHAM, etc.)

Figure 2. Considered land use changes, impacts on water resources, and analytical approaches used by the studies in the special section. SM is soil moisture, SW is surface water, GW is groundwater, and UZ is unsaturated zone.

3. Conclusion

[9] Land use and climate change are inexorably linked through the hydrologic cycle. The papers in this special section apply a variety of tools to past, present, and future time frames to understand the water resources impacts of land use change from watershed to global scales. All share a common thread in addressing one of the most fundamental questions about human sustainability.

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