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When trends intersect: The challenge of protecting freshwater ecosystems under multiple land use and hydrological intensification scenarios

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HIGHLIGHTS

- This paper considers the impacts of land use and hydrological intensification on inland waters
- Global issues are considered through the lens of Australian examples
- Likely scenarios include wet regions becoming wetter, dry regions drier and storms more intense
- The legacies of past land use change will need to be addressed
- Proactive governance based on innovative science and adaptive management will be critical

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ABSTRACT

Intensification of the use of natural resources is a world-wide trend driven by the increasing demand for water, food, fibre, minerals and energy. These demands are the result of a rising world population, increasing wealth and greater global focus on economic growth. Land use intensification, together with climate change, is also driving intensification of the global hydrological cycle. Both processes will have major socio-economic and ecological implications for global water availability. In this paper we focus on the implications of land use intensification for the conservation and management of freshwater ecosystems using Australia as an example. We consider this in the light of intensification of the hydrologic cycle due to climate change, and associated hydrological scenarios that include the occurrence of more intense hydrological events (extreme storms, larger floods and longer droughts). We highlight the importance of managing water quality, the value of providing environmental flows within a watershed framework and the critical role that innovative science and adaptive management must play in developing proactive and robust responses to intensification. We also suggest research priorities to support improved systemic governance, including adaptation planning and management to maximise freshwater biodiversity outcomes while supporting the socio-economic objectives driving land use intensification. Further research priorities include: i) determining the relative contributions of surface water and groundwater in supporting freshwater ecosystems; ii) identifying and protecting freshwater biodiversity hotspots and refugia; iii) improving our capacity to model hydro-ecological relationships and predict ecological outcomes from land use intensification and climate change; iv) developing an understanding of long term ecosystem behaviour; and v) exploring systemic approaches to enhancing governance systems, including planning and management systems affecting freshwater outcomes. A major policy challenge will be the integration of land and water management, which increasingly are being considered within different policy frameworks.

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1. Introduction

Intensification is a key characteristic of many emerging global 'megatrends'; trends that, on a global scale, will significantly shape the ecological, social, economic and cultural landscapes of the future (Hajkowicz et al., 2012). These include urbanisation, increasing mineral extraction and energy production and the requirement to obtain more resources from a declining natural resource base. A rising world population, forecast to be 9 billion people by 2043 (UNESA, 2012), increased wealth and changing dietary preferences suggest that global food production will need to increase by 70% by 2050 (Steduto et al., 2012). Potentially constraining this production is the threat of water scarcity. Vörösmarty et al. (2010), using a global geospatial framework, showed that pandemic impacts on both human water security and freshwater biodiversity were highly coherent, although not identical. Nearly 80% of the world's population (4.5 billion in 2005) was exposed to high levels of threat to water security, while 65% of global river discharge, and the aquatic habitats supported by river flows, were classified as moderately to highly threatened (Vörösmarty et al., 2010). The most serious impacts, which include watershed changes, pollution and water resource development, coincide in regions of intensive agriculture and dense human settlement. Already, the global agricultural sector accounts for 70% of withdrawals from freshwater systems and more than 90% of consumptive water use (Steduto et al., 2012). The direct and indirect competition for water resources associated with population growth will intensify both mild and moderate droughts.

Importantly, the impacts of land use intensification and increasing water demands have to be considered within the wider context of global climate change. Anthropogenically-driven climatic changes are already considered to pose a major threat to global biodiversity, including inland aquatic ecosystems and their species (Solomon, 2007; Woodward et al., 2010). Globally, freshwater ecosystems and biota are considered to be particularly vulnerable because of their physical fragmentation within terrestrial landscapes and relative isolation by catchment divides and saltwater barriers (Dudgeon et al., 2006). Many freshwater species will be unable to disperse to suitable habitats as temperatures increase and changes in precipitation disrupt migration and feeding and breeding patterns (Woodward et al., 2010). These climatically-driven changes will be accompanied by the direct and indirect effects of increasing human demands for water (Palmer et al., 2008). In regions where precipitation declines, surface and ground water resources and environmental flows will be increasingly contested. As a consequence, declining water availability will pose a significant threat to freshwater environments, as well as agriculture and human consumption. It is anticipated that by 2050, 2.3 billion people will be living in water basins experiencing severe water stress (OECD, 2012). The extent to which human communities will stay and adapt to declining conditions is difficult to predict. Most studies have focused on developing countries where mitigating circumstances, such as war and poverty, are present (Gemenne, 2011). Environmental extremes also cause hardships in developed countries, but the dynamic is likely to be different because of greater economic and political stability, and differences in agricultural technology.

The implications of the interacting trends of land use intensification and hydrological intensification for the management and conservation of freshwater ecosystems are the focus of this paper. We consider the evidence for hydrological intensification, the existing legacy of land use change on the water quality and hydrological regimes of Australian river systems, the likely interacting effects of land use and hydrological intensification and the need for proactive governance and adaptive management. We also suggest a set of priority research actions to integrate land use intensification into freshwater management and conservation.

2. Evidence for intensification of the global hydrological cycle

Associated with the broad trend in the expansion of the earth's population has been a major expansion of the global economy driven largely by the exploitation of fossil fuel resources and land clearing, resulting in an associated increase in carbon emissions (Canadell et al., 2007). The rate of growth in atmospheric emissions has increased from approximately 1.3% per year during the 1990s to 3.3% per year during the period 2000–2006 (Canadell et al., 2007). This trend is likely to continue despite growing efforts to curb global emissions. Global warming is a major consequence of rising concentrations of greenhouse gases and based on current emission trajectories, temperature rises between 4 °C and 6 °C appear likely by the end of the century (Bodman et al., 2013; Peters et al., 2013). Rising temperatures are a key driver of changes in global circulation patterns and are likely linked to the global phenomenon of hydrological intensification (Durack et al., 2012b; Held and Soden, 2006; Huntington, 2006; Wild et al., 2008). A consequence of warming in the lower atmosphere is an increase in its capacity to hold water. The Classius–Claperyon expression predicts that the saturated vapour pressure of the lower troposphere increases by about 7% for each 1-K increase in temperature. This response is robust in most climate models. A key outcome of this process is the predicted intensification of the hydrological cycle such that wet areas are likely to get wetter and dry areas drier (Wentz et al., 2007; Chou et al., 2013; Held and Soden, 2006).

Hydrological intensification will drive changes in the spatial and temporal distributions of water resources and an increase in the frequency and intensity of extreme events such as tropical storms, floods and droughts (Fig. 1). Disparate observational data sets generally predict that warming will likely result in increases in evaporation and precipitation, although there is little supporting evidence for predicted increases in the frequency and intensity of tropical storms and floods (Huntington, 2006). Attention is now focussed on developing an improved observational evidence base for hydrological intensification.

An analysis of a network of 355 rain gauges across China for the period 1960–2000, for example, found that although there was no trend in the country-wide average rainfall, rainfall in the drier north-eastern regions of China had declined by approximately 12% since 1960, with declines mostly occurring in summer and autumn. In contrast, rainfall in southern China increased, particularly during summer and winter (Piao et al., 2010b). Associated analysis of stream flow records revealed a weak trend for increasing runoff in the Yangtze River in southern China and a significant decline in river runoff in the Yellow River in northern China. Direct attribution of changes in runoff to changes in precipitation regimes in both rivers, however, was problematic owing to the intense human pressure on water resources (Piao et al., 2010b). Examination of rainfall and discharge records for the Amazon have also revealed a marked increase in river discharge associated with an increase in the Amazon basin integrated precipitation, a trend consistent with intensification of the hydrological cycle (Gloor et al., 2013). Treydte et al. (2006) used tree ring analysis to construct a millennium scale precipitation record in northern Pakistan. They found dry conditions at the beginning of the last millennium and through the 18th and 19th centuries, with a trend for increasing precipitation in the latter half of the 19th century and throughout the 20th century, which tracks the initiation and expansion of the industrial revolution.

There is also evidence for intensification of the hydrological cycle in ocean surface salinity data. Sea surface salinities in the ocean are widely measured and are used to interpret changes in the fluxes of freshwater, freshwater transport and local ocean mixing, key components of climate dynamics (Curry et al., 2003; Durack et al., 2012a). Examination of trends in ocean salinities from the 1950s to the 1990s along a transect through the western Atlantic spanning 50°S to 60°N revealed systematic freshening at both poleward ends and increasing sea salinities at low latitudes (Curry et al., 2003). Durack et al. (2012a) observed similar trends in ocean salinities and concluded that broad belts of increasing salinities through the tropics, with areas of freshening in mid and high latitudes, provided robust evidence for an intensification of hydrological cycles at a rate approximately double that predicted by climate models.

Thus several lines of evidence suggest intensification of the global hydrological cycle. Global climate models also predict that this pattern