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Global analysis of river systems: from Earth system controls to Anthropocene syndromes

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Continental aquatic systems from rivers to the coastal zone are considered within two perspectives: (i) as a major link between the atmosphere, pedosphere, biosphere and oceans within the Earth system with its Holocene dynamics, and (ii) as water and aquatic biota resources progressively used and transformed by humans. Human pressures have now reached a state where the continental aquatic systems can no longer be considered as being controlled by only Earth system processes, thus defining a new era, the Anthropocene. Riverine changes, now observed at the global scale, are described through a first set of syndromes (flood regulation, fragmentation, sediment imbalance, neo-arheism, salinization, chemical contamination, acidification, eutrophication and microbial contamination) with their related causes and symptoms. These syndromes have direct influences on water uses, either positive or negative. They also modify some Earth system key functions such as sediment, water, nutrient and carbon balances, greenhouse gas emissions and aquatic biodiversity. Evolution of river syndromes over the past 2000 years is complex: it depends upon the stages of regional human development and on natural conditions, as illustrated here for the chemical contamination syndrome. River damming, eutrophication and generalized decrease of river flow due to irrigation are some of the other global features of river changes. Future management of river systems should also consider these long-term impacts on the Earth system.

Keywords: global change syndromes; rivers; water resources; Anthropocene; chemical contamination

1. INTRODUCTION

Since the Dublin Conference on water in 1992 and the development of global change programmes in the 1980s, water-related issues have figured prominently both in international sustainable development agenda and in Earth system science programmes. It is increasingly recognized that the continental aquatic systems that were controlled by Earth system drivers, such as climate, relief, vegetation, and lithology, are now also controlled by social, societal and economic drivers, such as population growth, education, urbanization, industrialization, water engineering, and international environmental regulation (Vitousek *et al.* 1997*a*; Vörösmarty *et al.* 1997*a*; Schellnhuber & Wenzel 1998; Messerli *et al.* 2000; Ehlers & Kraft 2001; Tyson *et al.* 2002; Kabat *et al.* 2003). In many regions of the world the Earth system components are now more controlled by anthropogenic forcing than by natural drivers (Turner *et al.* 1990; Messerli *et al.* 2000), a status that characterizes the Anthropocene era (Crutzen & Stoermer 2000). It was Vernadski (1926) who coined this concept at a time when human pressures were still very limited.

A major breakthrough in our understanding of Earth system–human impact interactions has been made by Turner *et al.* (1990) in the publication '*The Earth as transformed by human action*', which included several chapters on river transfer alteration. Other relevant attempts to bridge the gap between an Earth system analysis of continental aquatic systems and a water resource management analysis have been noted in the recent valuation of environmental services given by wetlands, lakes, rivers, groundwaters (Costanza *et al.* 1997), the combination of ecosphere and anthroposphere components (Vellinga 1996) and the decomposition of human–natural system interactions using the DPSIR analysis, particularly for coastal ecosystems (Salomons *et al.* 1999; Turner *et al.* 2001; Von Bodungen & Turner 2001). Risk and vulnerability analysis is another fast-growing interdisciplinary domain linking Earth system and socio-system analysis. In the synthesis of the GACGC (2000), 16 syndromes of human pressures leading to global change have been described, many of them related to aquatic systems.

In a scenario of global warming and modified climate variability, increased population and economic growth for the next 100 years, water demand and flood control demand will rise (Falkenmark 1997, 1998). Water resources will be exposed to increasing withdrawal, storage, flow regulation and consumptive use by evaporation and transpiration, and to pollution (Falkenmark & Lundqvist 1995; Lundqvist 1998); also, in some regions, the water availability, both on an annual run-off and on a seasonal flow basis, is likely to change markedly because of global climate change (Kabat *et al.* 2003). The security of future water resources is now threatened (Falkenmark & Lundqvist 1998).

This paper is an attempt to analyse and synthesize on the global scale the role and change of continental aquatic systems, particularly the river systems within the Earth

One contribution of 11 to a Theme Issue 'Freshwater and welfare fragility: syndromes, vulnerabilities and challenges'.