Chapter D.4

Responses of Continental Aquatic Systems at the Global Scale: New Paradigms, New Methods

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D.4.1 Introduction

Water figures prominently in the science of the Earth system and in the international agenda on global change. As a key component of the Earth's climate and biogeochemistry the global hydrological cycle has received significant attention with respect to its role in land-atmosphere exchanges of water, energy and CO_2. This subject has, for this reason, constituted a major portion of this book. Water is also a key vehicle in the global mobilisation and transport of carbon, nutrients and suspended sediment, and it is these horizontal fluxes that orient major interconnections between the continental land mass and the world's oceans. We shall focus in this chapter on the terrestrial water cycle and its role in the horizontal transport of land-derived materials which has been voiced as an Earth system and global change issue several times within the IGBP (Pernetta and Milliman 1995; Vörösmarty et al. 1997a). We refer here to "terrestrial aquatic systems" for rivers, lakes, reservoirs, wetlands and groundwaters while using "continental aquatic systems" to include the former as well as deltas, coastal lagoons, estuaries, fjords, etc.

Despite the enormous emphasis placed on climate change in the international research agenda on global change (e.g. Houghton et al. 2001; US National Assessment 2000; Lemellä and Helenius 1998) the dialogue with respect to continental aquatic systems (CAS) must necessarily extend to other human dimensions issues including land cover change, population growth, urbanisation, economic development, and water resources management (Fig. D.42). Not only are issues within each conceptual domain important to understand, but their interactions are as well. As an example of the complexities which may arise, consider a major change in land

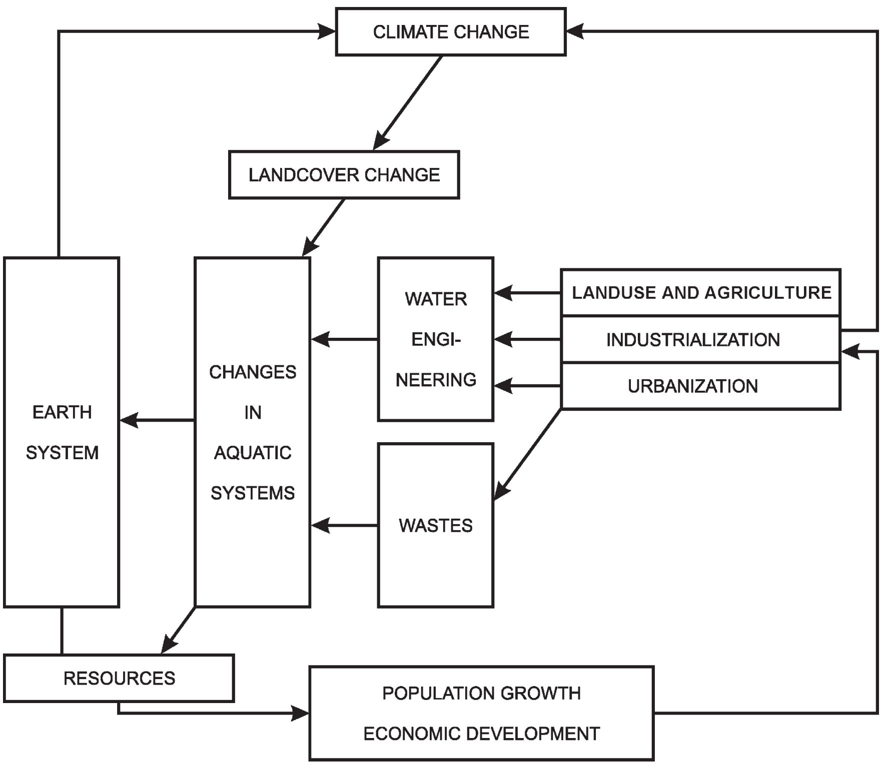

Fig. D.42.
Elements of global change with respect to global river systems for hydrology and nutrient biogeochemistry. The interactions of climate change and variability, land cover change, population growth and industrialisation, and water engineering are shown

cover from forest to agriculture that creates elevated erosion upstream which then translates into siltation of downstream reservoirs, forcing construction of additional reservoir systems. These impoundments promote consumptive use of water through new irrigation schemes that further fragment the landscape and change local weather patterns. Changes in the reliability of weather for crops then prompts additional reservoirs to be constructed, which begins to compromise water quality, interfere with the migration patterns of economically important fisheries, and distort the seasonalily of nutrients delivered to the coastal zone and so forth.

Both hydraulic engineering and extensive land cover change makes it increasingly difficult to detect the signature of climate change on global water resources (Vörösmarty 2002). Nonetheless, we hypothesise that while their aggregate effect is difficult to quantify with precision, such contemporary changes are now pandemic in nature. We arrive at this conclusion from documentary evidence and modelling studies available in the recent literature which will be presented in this section of Part D.

Over continental and global domains, the aggregate impact on the terrestrial water cycle of water resource management exceeds that of land cover/use and climate change in the relatively recent past and will continue for the next several decades (i.e. ±50 years from present).

We recognise that this flies in the face of current studies of global change which emphasise the importance of the climate change effect alone – witness the Intergovernmental Panel on Climate Change, US National Assessment, the US Global Change Research Program funding (Subcommittee on Global Change Research 2000), etc. (when we refer to *climate change* here we mean as climate variability, natural climate change, anthropogenic climate change due to enhanced greenhouse effect). We also recognise that the absolute and relative impact of each of the three effects will be site and region-specific.

The goal of this part of the text is to assess the validity of our contention given above, to review emerging subsidiary hypotheses, tools, and datasets. We also will review in detail the evidence for our overall assessment of the relative importance of different key agents of global change – climate change, land cover/land use change, and water engineering.

We will attempt to identify key unknowns and offer our assessment of likely changes into the future. We will use, as appropriate, global-scale observations and key geospatial biophysical datasets currently available. There is a growing body of knowledge now formalised into a set of aggregate relationships linking constituent fluxes and biophysical attributes of continental water systems. Together these methods constitute a new state-of-the-art in river basin analysis for water and constituent fluxes. These merit our due attention and, in fact, are essential to formulating a new paradigm regarding global-scale changes to river systems.

D.4.2 Terms of Reference

D.4.2.1 Relevant Time and Space Scales Associated with Global Change and Continental Aquatic Systems

The hydrosphere is influenced by global change over a variety of scales and is closely tied to the state of the climate system. Thus, its natural variability is associated with periodicities that span several temporal domains – from long-term oscillations associated with the Milankovic cycle of eccentricity in Earth orbits around the sun (~ 10^4 yr) to much shorter quasi-periodic events such as El Niño/Southern Oscillation, North Atlantic Oscillation, Arctic Oscillation (~ 10^0–10^1 yr). Still higher-frequency and episodic events characterise hydrology, especially over local domains. Additional concerns surround the impact of progressive climate change over the decades-to-century time domain, together with associated increases in climate extremes that are postulated to occur. These drive debates on the very nature and thresholds associated with glaciation and de-glaciation, as well as the vulnerability of human population to flooding and drought.

During the Holocene, climate and tectonics were the key determinants of the state of river basins. The situation has recently changed due to the introduction of significant human impacts on the Earth system. Throughout history, humans have pursued very direct and growing roles in shaping the character of the terrestrial water cycle, as they harness and use elements of continental aquatic systems in service to society. Recent changes have moved us rapidly toward a global-scale impact that is only now being articulated. For instance, it is now recognised that humans control and use a significant proportion (> 50%) of continental runoff to which they have access (Postel et al. 1996). And, the impact of the hydraulic engineering needed to afford such control has substantially distorted continental runoff (Vörösmarty and Sahagian 2000; Rosenberg et al. 2000). Large reservoir construction alone has doubled or tripled the residence time of river water, with the mouths of several large rivers showing delays on the order of months to years (Vörösmarty et al. 1997b). Such regulation has enormous impacts on suspended sediment and carbon fluxes, waste processing, and aquatic habitat (Dynesius and Nilsson 1994; Vörösmarty et al. 1997b,c; Stallard 1998). Land cover change also has been shown to influence local patterns of runoff and feedbacks to the atmosphere as discussed earlier.

The emphasis in this section will be on macro-scale domains. However, because our knowledge of aquatic system change is better articulated at more local and regional domains, we will identify sensitive systems using the more traditional literature as required through-