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Non-linear interactions of urban and freshwater systems: Exploring implications for sustainability and water planning and management

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Human population is progressing into a predominantly urban configuration. Currently, 3.5 billion people – 55% of the total human population – live in urban areas, with an increase to 6.68 billion (68%) projected by 2050. In this progressively more populated world, a central issue of sustainability assessments is understanding the role of cities as entities that, despite their comparatively small physical footprint (less than 0.5% of the global area) demand resources at regional and global scales.

Many of the resources that sustain urban population directly depend on the freshwater system: from direct fluxes from/to the immediate environment of cities for water supply or waste elimination, to water-dependent activities like biomass (food, biofuels, fibers) and energy production. Urban and freshwater system interactions are subject to multiple sources of non-linearity. Factors like the patterns of size or spatial distribution and interconnection of groups of cities; or the nested and hierarchical character of freshwater systems, can vastly influence the amount of resources required to sustain and grow urban population; likewise, equivalent resource demands can be met through different management strategies that vary substantially in their cumulative pressure exerted on the freshwater system.

Here we explore the non-linear character of those interactions, to i. identify water management options to avoid, minimize or offset regional impacts of growing urban populations, and ii. explore long term implications of such non-linearities in sustained resource base of urban areas. We propose a framework integrating three elements: 1. properties of the size and spatial distribution of urban center sizes, 2. scaling regime of urban energy resource dependencies, and 3. scaling regime of associated physical and ecological impacts in freshwater systems.

An example of this approach is presented in a case study in the Magdalena River Basin – MRB (Colombia). The basin covers nearly one quarter of Colombia's national territory and provides sustenance to 36 million people, with three quarters of basin inhabitants living in medium to large urban settlements of populations of 12 000 or more inhabitants and 50% concentrated in the 15 largest cities. The case study results indicate that freshwater-mediated resource dependencies of

urban population are described by a linear or super-linear regime that indicates a lack of scale economies, however, freshwater systems' capacity to assimilate those resource demands is characterized by a sublinear regime. As a result, current practices and technological approaches to couple freshwater and urban systems will not be able to withstand the resource demands of mid-term future population scenarios. Our approach allows to quantify the projected gaps to achieve a sustained resource base for urban systems in MRB.