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# River Basins under Anthropocene Conditions

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## ABSTRACT

Despite major progress over the last thirty years, our knowledge of riverine fluxes in human-impacted basins (pollutants, nutrients) is still limited to a few descriptors of water quality. River flux surveys need to be optimized, particularly in terms of the sampling frequency and particulate matter, to consider the residence time of many pollutants. Concentrations versus water discharge relationships can be set up for that purpose. In the absence of long-term flux, sediment profiles of elements and compounds can be used as environmental archives to determine the relative fluxes of metals, persistent organic pollutants, and some nutrients over time scale of decades to centuries. From the few well-documented flux records, several types of trends can be discerned:

1. steady state for many ions and particulate metals not affected by anthropogenic activities,
2. moderate and regular increase of some major ions,
3. fast increase, exceeding one order of magnitude, for descriptors affected heavily by anthropogenic activity, such as $NO_3^-$ in many rivers and metals in some of them,
4. sudden occurrence of xenobiotic substances,
5. bell-shaped trends when pollution reduction has been successful (e.g., $NH_4^+$, $PO_4^{-3}$, $BOD_5$, COD, and most metals in the Rhine),
6. slow decrease in dissolved silica for biologial uptake by aquatic biota,
7. stepwise decrease of total suspended solids (TSS), particulate nutrients, and pollutants due to reservoir storage after damming.

Whole-basin flux models combining hydrological and biogeochemical processes are now being developed and used to explore future scenarios or to reconstruct past long-term patterns in evolution.

Although riverine fluxes of pollutants, nutrients, and carbon species are now considered in environmental studies, they have long been regarded as minor indicators compared to riverine concentrations, on which most water quality criteria are based (Chapman 1992). Geochemists were the first to compute river fluxes systematically as a measure of land erosion, on one hand, and of inputs to oceans, on the other (Livingstone 1963). In the 1960s, limnologists working on eutrophication started to

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link systematically the primary productivity to the total amount of phosphorus received per unit area of water body. This new approach was developed, in particular, by Richard Vollenweider in his 1968 report for the Organisation for Economic Co-operation and Development. This report, written by a hydrobiologist, focused on riverine fluxes, their sources, and sinks. These concepts, however, had already been developed by F.A. Forel, eighty years before, when he measured inputs from the Rhône River to the Léman in the founding stage of limnology, the "oceanography of lakes."

In this chapter, the evolution of riverine fluxes during the Anthropocene is discussed. Anthropocene is a term recently coined by Crutzen and Stoermer (2000). It is the current geological epoch when the growing impacts of human activities on the Earth's system are equal to the natural forcing. Although these authors assign Watts's invention of the steam engine (1784) as the starting point of the Anthropocene, I prefer to refer to 1950 as the key date for its full development, i.e., the point at which many indicators of human impacts (e.g., land use, dam constructions, urbanization, $CO_2$ increase, waste release) reached a global extension.

## RIVER FLUX SURVEYS

Rivers contain naturally occurring compounds, such as major ions (e.g., $Ca^{2+}$, $HCO_3^-$), plant nutrients ($SiO_2$, $NO_3^-$, $NH_4^+$, orthophosphates), organic compounds (e.g., humic acids and hydrocarbons), and xenobiotic substances (synthesized by humans). In these latter substances, thousands of products or by-products can be found at very low concentrations (ng $l^{-1}$ to µg $l^{-1}$) but possessing toxic properties. They are, therefore, termed organic micropollutants (e.g., pesticides, polyaromatic hydrocarbons [PAH], polychlorobiphenyls [PCBs], solvents). When they are very stable in the aquatic environment or in soils, they may not degrade for years and can eventually accumulate in either sediments, soils, or even higher organisms. These specific compounds are now termed persistent organic pollutants (POPs). Metals — particularly the heavier metals, such as lead (Pb), cadmium (Cd), mercury (Hg), zinc (Zn), chromium (Cr), and copper (Cu) — as well as some nonmetallic elements, such as arsenic (As), antimony (Sb), and tin (Sn), are naturally found in rock-forming minerals. Variability in weathering and erosion processes causes large natural variations in the background concentration of these elements. When concentrations of these elements are elevated by human activities to toxic levels (for biota and humans), they are termed inorganic micropollutants, often simplified as heavy metals. Major ions, metals, nutrients, and carbon species that reach harmful levels from the human perspective by natural processes (variability) cannot be considered pollutants. Natural variability in concentrations over several orders of magnitude are observed dependent on individual chemical indicators and compounds as well as on river basin size (Meybeck et al. 1989; Meybeck 1996; Kimstach et al. 1998). This variability is one to two orders more at finer spatial scales (<100 $km^2$) than found at the coarsest scale (> $10^6$ $km^2$).

By considering both the current river quality surveys, for example, those collected at the global scale by the UNEP GEMS/WATER Programme (United Nations Environment Programme Global Environmental Monitoring System/Freshwater Quality Programme), and academic studies, we can obtain an overview of current knowledge of riverine geochemistry and water quality (Table 17.1). Despite considerable efforts to improve the quality of river surveys in some locations over the last 10 to 15 years, concentration of many elements are not or are only insufficiently known, particularly those for micronutrients (metals) and organic pollutants (Table 17.1).