The IGBP Water Group: a response to a growing global concern

by Michel Meybeck

The interdisciplinary IGBP Water Group has been created in 1998 to coordinate and promote IGBP research to understand the role of continental aquatic systems – rivers, lakes, wetlands, estuaries, groundwater, and coastal zones – in the biogeochemical functioning of the Earth system. The IGBP Water Group emphasizes mainly the changing fluxes, levels, and transfers of water, sediment, carbon, and nutrients, such as nitrogen, phosphorus, and silicon. Other important water quality determinants like heavy metals and persistent organic pollutants are not ruled out. A multidisciplinary approach that requires input from all IGBP Programme Elements and cooperation with other international programmes, such as IHDP, is needed as water issues concern both natural and social systems.

Global issues related to continental aquatic systems

Continental aquatic systems are here defined from the point where precipitation reaches the Earth's surface until it reaches the sea in full marine conditions (for the exorheic regions) or until it reaches the final base level in closed basins (endorheic regions). The downstream boundary of this realm is variable in time and space and includes what is commonly defined in IGBP as the coastal zone.

The fluvial systems are exposed to two types of major global changes: climate change and direct anthropogenic changes in land use and water use, such as river damming and channelization, agriculture, irrigation and water transfer, industry and mining, and urbanization and population growth (see Table 1). Their multiple impacts on physical, hydrological, chemical, and biological processes affect the levels, fluxes, and occurrence of continental water resources, river-borne material and aquatic biota, as well as their time and space distribution. Most of these impacts are now observed on a global scale. Some of these observations (see Notes, 1, 2, 3) are recent, like the occurrence of persistent organic pollutants. Others have been taking place over a longer period of time, such as for the impacts on fluvial systems resulting from agriculture (4, 5).

The influence of climate change on river networks and riverine fluxes is a permanent and prominent feature of the Earth's surface dynamics during geological times, yet the acceleration of climate variations due to anthropogenic activities may result in a faster response of all continental waters.

Direct human impacts on aquatic systems are of a more local or regional nature. However they may occur even in desertic and / or remote regions of the world, through river damming, mining and smelting operations, deforestation, and long-range atmospheric transport of SO_2, NO_x and micropollutants. In regions still sparsely populated like some in Canada, Siberia, Amazonia, Equatorial Africa, and New Guinea, evidence of severe human impacts on aquatic systems can be found (6, 7, 8).

In turn, these impacts on continental aquatic systems result in numerous global issues (see also Table 1):

(A) **human health** through the development of water-related diseases, like malaria and bilharzia, water-borne diseases like cholera and other pathogens, the increase of chemicals in drinking water, the toxic algae development resulting from eutrophication;

(B) **water availability** through enhanced evaporation, development of water use transfer mainly for agriculture, fragmentation of river networks;

(C) **water quality** for domestic, agricultural, and industrial uses resulting from salinization, eutrophication, increase of chemical inputs;

(D) **global carbon balance** through the storage of organic and inorganic dissolved and particulate carbon species, the destorage of organic carbon (permafrost melt), the global change in silicate minerals weathering by atmospheric CO_2;

(E) **fluvial morphology** as shift of river courses, erosion or sedimentation in river beds;

(F) **aquatic biodiversity** through the general loss of pristine headwaters, the segmentation of river networks, the change of water quality;

(G) **coastal zone impacts** from the modification of sediment transport, the enhanced inputs of nutrients and related eutrophication, the increasing levels of pollutants and of microbial pathogens (2, 9, 10, 3, 11, 12) (see examples in box on page 10).

Existing or planned IGBP activities on continental aquatic systems

From the recent science and implementation plans of the IGBP Programme Elements and from inter-Programme Element collaboration, a first list of IGBP activities related to continental aquatic systems and their recent or future modification can be drawn. They are mostly related to items (B), (C), (D), (E), and (G) of the above list of global issues and may provide major insights on other global issues (A) and (F) that are more relevant to IHDP and DIVERSITAS.

- LUCC (with IHDP) – Fluvial system response to global change for large catchments; change of transport of sediments, carbon and nutrients; impacts of dams / reservoirs and wetland drainage.
- GCTE-IGAC Task Force on N dynamic model (including denitrification).
- GCTE – Activity 1.2 database on N atmospheric deposition; database on fertilization of agricultural soils; global data base on litter chemistry; 3.3.1. Global Soil Organic Matter database (with IGBP-DIS, LUCC, and FAO); 3.3.2. Global soil erosion map; 4.3.2. Land-use and global change impacts on biodiversity and ecological complexity (with DIVERSITAS).
- PAGES – 1.2.1 and 1.3 Changes in

Table 1 Major global threats on continental aquatic systems and related issues

Environmental state changes	Major impacts	A	B	C	D	E	F	G
				Global Issues				
1. Climate change	development of non-perennial rivers		●	●	●	●	●	●
	segmentation of river networks					●	●	
	development of extreme flow events		●			●	●	●
	changes in wetland distribution	●	●	●	●		●	●
	changes in chemical weathering				●			●
	changes in soil erosion				●	●		●
	salt water intrusion in coastal groundwater		●					
	salinization through evaporation		●	●			●	
2. River damming and channelization	nutrient and carbon retention				●			●
	retention of particulates				●	●		●
	loss of longitudinal and lateral connectivity						●	
	creation of new wetlands	●		●	●		●	
3. Land-use change	wetland filling or draining			●	●		●	
	change in sediment transport				●	●		●
	alteration of first order streams					●	●	
	nitrate and phosphate increase	●		●	●			●
	pesticide increase	●		●				●
4. Irrigation and water transfer	partial to complete decrease of river fluxes					●	●	●
	salinization through evaporation		●	●				
5. Release of industrial and mining wastes	heavy metals increase	●		●				
	acidification of surface waters			●			●	
	salinization	●		●			●	
6. Release of urban and domestic wastes	eutrophication	●		●	●		●	●
	development of water-borne diseases	●						
	organic pollution	●		●			●	
	persistent organic pollutants	●		●				●

A: human health; B; water availability; C: water quality; D: carbon balance; E: fluvial morphology; F: aquatic biodiversity; G: coastal zone impacts. Only the major links between issues and impacts are listed here.

watershed hydrology (Baikal Drilling Project; PEP III, etc.); 3.1 Human impacts on fluvial systems (past and present origins and controls of riverborne fluxes; feedbacks on human society and biogeochemical cycles; changes in the fluxes of water, sediment, nutrients); 4.2 Palaeoclimate modelling and mapping at 2, 6, and 21 kaBP; BIOME-6000 (with IGBP-DIS/GAIM/GCTE); 5.2.1 Isotopic variations in river outflows.

- GAIM – Water cycle/Water management modelling (partial list).
- BAHC – 4. Mountain hydrology and ecology: (processes, global change impacts, sustainable development); 5. Impact of environmental change and climate variability on water resources (risk/vulnerability assessment; impact on water quantity and quality; feedbacks on climate); 8. Influence of climate change and human activities on mobilization and transport of matter through riverine systems (past, present, and future, controlling factors on water, sediment, C, N, P, Si transport); 9. Aggregated databases on land cover and soil characteristics.
- LOICZ – 1. Catchments basin dynamics and delivery of nutrients, carbon, and sediments to the coastal zone; 4. Economic and social impacts of global change in coastal systems including riverine inputs of nutrients and pollutants.
- LBA (Large Scale Biosphere-Atmosphere Experiment in Amazonia) – Qualitative and quantitative behaviour of Amazonian rivers both in pristine conditions and in deforested area.

As can be seen a great amount of topics are related to fluvial processes and fluxes, to the origins of their modifications and to their impacts on the coastal zone. It must be noted that present day fluvial transport of water sediment and nutrients is explicitly targeted by PAGES, LOICZ, and BAHC. This apparent overlap may actually be regarded as intentional and resulting from a joint workshop of these three Programme Elements held in Durham, New Hamsphire (13). This meeting was actually the founding stone of the IGBP Water Group and was followed by a smaller working session in Brussels in November 1997 (14) from which the following section summarizing the proposal for the IGBP Water Group activity is mostly derived.

Propositions for the IGBP Water Group activities

The primary goal of the IGBP Water Group is to understand the role of continental aquatic systems in global biogeochemical cycles and how the fluxes of materials associated with them (water, sediments, nutrients, pollutants) have been influenced by and responsive to global change of climate and land use over past, present and future time frame.

Considering the multiple facets of this goal and the existing IGBP activities in this field, six main questions were selected:

1) What are the present-day stocks, concentrations, and flux fields of fresh water-borne material (from atmosphere through terrestrial ecosystems and societal systems) to the ocean?
2) What is the partitioning of water and water-borne material stocks and fluxes, due to the influence of natural variabi-lity vs. human perturbations ? To what extent have humans affected these global fluxes?
3) How do biogeochemical processes affect these fluxes through continental aquatic systems?
4) Which aspects of freshwater-related biogeochemical processes and fluxes are most sensitive to projected future changes in material supply and water stocks / fluxes?
5) To what extent do changes in global continental aquatic levels and fluxes affect ecosystems function and water resource utility and sustainability?
6) To what extent do changes in global continental aquatic fluxes affect the Earth system?

These questions are primarily addressed to nutrients (N, P, Si) and carbon, some of the best documented water-borne elements, and may eventually concern other water-borne materials as heavy metals and persistent organic pollutants.

In seeking answers to these questions, all IGBP Programme Elements are concerned, from the atmosphere to the open ocean (Figure 1). The past evolution of continental aquatic systems due to climate change and land-use change will be covered by PAGES at several time scales from centuries to millennia. IGBP-DIS will be used to manage and disseminate the databases generated by the IGBP Water Group. GAIM and START could develop special tools and training programmes for integrated water management, taking into account both local and global issues.

A set of operational and research needs has been identified for the fulfilment of these objectives, including: (i) generation of datasets; (ii) establishment of global typologies of aquatic systems; (iii) modelling of processes and fluxes; (iv) coupling the biogeochemical response to the socio-economic development; and, (v) using palaeorecords to decipher past natural evolution from anthropogenic impacts.

Datasets

The IGBP Water Group's success will greatly depend on the development of global datasets at appropriate resolutions (30' to 1° should be a first target). Regional datasets for case studies (e.g. Western Europe, Amazon, Arctic Ocean Watershed, Mediterranean Watershed, South East Asia) could also be generated. These datasets should be standardized, geographically referenced, and take into account watershed boundaries of rivers, great lakes, regional seas, and oceans including: (i) topography, lithology, land cover, and climate; (ii) surface runoff and groundwater input, water engineering works, hydrogeographic attributes, and irrigation rate; (iii) political and administrative boundaries, population density, sewage collection and treatment rates, indices of agricultural and industrial development, land use, fertilizer use, and livestock density, etc.; (iv) NO_x and SO_2 deposition, and micropollutants atmospheric fallout.

Numerous global datasets have already been developed by LOICZ, UNESCO-IHP, UNEP/WHO GEMS-Water Programme, the International Lake Environment Committee, etc.

It is essential that socio-economic data should be obtained at the appropriate level (i.e., less than 100,000 km^2) and not aggregated per country, particularly for the most extended ones (A>1 Mkm^2) that can be highly heterogeneous in land use, population distribution, and water demand.

Additional data development includes: (i) time series data for selected rivers concerning water discharge (target >50y), sediment discharge (>20y), and water chemistry (>20y); (ii) intercomparison of case studies for which both water and material fluxes and socio-economic indicators are known and coupled (>20y); and (iii) development of sensor systems targeted to water quantity (precipitation, evapotranspiration, soil wetness) and quality (suspended particles, pigments, dissolved organic matter).

Some regional to global changes on continental aquatic systems

The Amu Darya river and the Aral Sea are not the only continental aquatic systems dramatically affected by change in river flow regime, the Nile (draining 2.8 M km^2), the Colorado (0.6 M km^2) are not discharging any more water, nutrients or sediments to the coastal zone. Actually several of the world's largest rivers are already impacted by large dams and/or water diversion (Columbia, Missouri, Rio Grande; Orinoco, Paraná; Volta, Niger, Nile, Orange, Zambezi; Indus, Huang He, Chiang Jiang, Ob', Yenisey, Syr Darya; Volga, Don, Dnepr, Danube, Murray). This results in a global sediment and particulate organic carbon trapping estimated to 20 % (16), and in a global aging of river water transfer, exceeding one year for many fluvial systems (17). Many of them are also channelized for navigation purposes. The present day global area of reservoirs is estimated to 500,000 km^2 and their volume to 6,000 km^3. River course artificialization and break of longitudinal connection is now widespread in the Northern Hemisphere where it has already affected the biodiversity of aquatic systems, particularly for fish species (18).

Due to multiple pollution sources the dissolved inorganic nitrogen and phosphorus inputs to the coastal zone at the global scale have been multiplied by a factor 2.5 and 2.0 respectively (19) while dissolved silica may have decreased as a result of riverine eutrophication, as for the Mississippi river (20). In some regions (e.g. Western Europe), N and P fluxes have already increased by an order of magnitude. Although less documented, similar trends are likely for some toxic metals as Cd, Hg and, to a lesser extent, Zn and Pb. Numerous persistent organic pollutants as PCBs, PAHs, and even DDT, still in use in many countries, are now found in aquatic systems.

In the next 25 years the average country water demand will increase by a factor 1.4 to 2.9 for developed countries and from 3 to 10 for developing countries. Irrigation is the most important water user and consumer, as 50 ha of irrigated land are needed to feed 1,000 capita in arid regions: the global irrigated area will increase from 2.54 to 3.30 M km^2 in 2025 (21). The municipal water use, where it exists, is highly heterogeneous from 10 to 500 l d^{-1} cap^{-1}. About 61 % of the withdrawn water (3,750 km^{3}y^{-1}) is consumed, i.e. evaporated, more than 5 % of the global river input to the ocean (21); this proportion is much higher for some regional seas such as the Mediterranean.

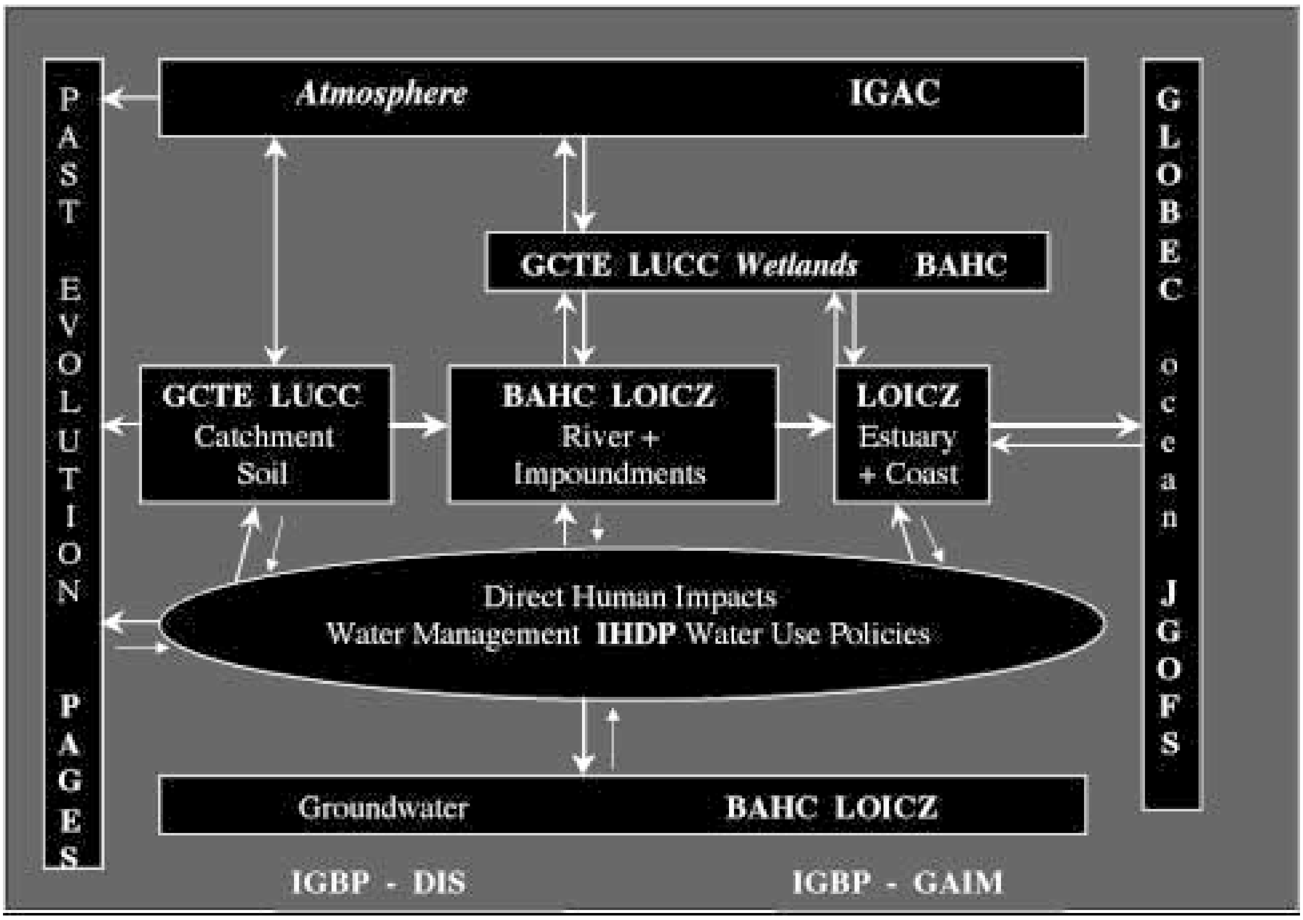

Figure 1. General frame of the IGBP Water Group

Typologies

River typologies are needed to describe and map: (i) the coupling between water and water-borne material circulation at the global scale; and (ii) the relationships between these circulations and socio-economic factors. The first set of typologies concerns the geochemical information with respect to lithology, relief, climate, soil and vegetation, structure of the fluvial network, etc. The second set concerns the alterations of this geochemical coupling by human activities as listed in Table 1. The socio-economic factors are the indicators of economic production, of environmental policies and of their actual enforcement, and of the historical development of anthropogenic pressures and impacts (15). The time scales of environmental and social responses, days to hundred years, are a critical aspect of these typologies. The river basin typology already started in BAHC will be coupled to the coastal zone typology developed by LOICZ.

Use of palaeorecords

Natural archives of past biogeochemical states and fluxes include peat, lake, reservoir, flood plain and coastal sediments. Their analysis can provide insights on river basin conditions of changing climate, soil and vegetation, and land use. Some of them can also provide records of atmospheric inputs, pH variations, eutrophication, and sediment inputs and sources (4, 5, 13).

Groundwater, under favourable conditions, may also act as a climatic and environmental archive. Ice cores have also been widely used since two decades to decipher the archives of long range atmospheric pollutants fallout.

Models

Different types of models have to be set up to predict fluxes, sources and sinks of water and water-borne material, particularly for highly reactive components as nutrients and carbon, or for particulates which are not continuously transported along continental aquatic systems. These models can be either static or dynamic, they include sub-catchment loading models based on land cover and/or land use, biogeochemical process models within the aquatic system, water and sediment transport models. Such models already exist at the local scale (i.e., river basin of 10^5 km^2) for organic carbon and nutrients and are being developed at the regional scale (10^6 km^2).

Framework of the IGBP Water Group

The IGBP Water Group concerns all IGBP Programme Elements (Figure 1). All of them have been asked to nominate a focal point to the IGBP Water Group and BAHC has been required by the SC-IGBP to host the IGBP Water Group. Its first task is to establish working links for the exchange of information between IGBP Programme Elements and to update, integrate, and disseminate the list of existing activities. The second task will be to identify a set of common products of the IGBP

Water Group and the relevant means, like workshops, to achieve these goals. These questions will be debated in detail at the Second IGBP Congress at Shonan Village, Japan, May 1999, during a specific working session. A scientific session will also be organized at the Second IGBP Congress for the IGBP Water Group, its topic will probably be the typology of continental acquatic systems.

The IGBP Water Group activities can also be considered as an IGBP link with other international programmes or institutions concerned with global water issues and riverine fluxes as GESAMP (IMO / FAO / UNESCO-IOC / WMO / WHO / IAEA / UN / UNEP), GEMS–Water (UNEP / WHO / UNESCO / WHO), UNESCO IHP, SCOPE Phosphorus and SCOPE Nitrogen (ICSU), IUCN, WWF, DIVERSITAS (IUBS / SCOPE / UNESCO / ICSU / GCTE / IUMS), Global Water Initiative.

The specificity of the IGBP Water Group is to consider the water related issues at a global scale combining both the impact of climate change and those of direct human activities: databases, typologies, models that will be developed for assessing the fluvial responses are targeted to be at the regional to global scale. It is anticipated that the IGBP Water Group's activities and products will be valuable contributions to other water-related programmes, and / or can be set up with their collaboration. Specific links with some of them have already been established.

A special mention should be made of the International Human Dimension Programme on Global Environmental Change (IHDP) which should be closely associated with the IGBP Water Group activities. Human dimensions have been explicitly pointed out in the topics related to water from BAHC, PAGES, LOICZ and LUCC: man can greatly modify the continental aquatic systems, but in turn their modification may severely limit his social and economic development.

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