NWO – WATER programme

04-SAA

RATIONALE OF THE PROGRAMME

“System Earth” is one of the main themes in the NWO strategic plan for 2002-2005. Against the background of the enormous impact of man on the earth system, this theme aims to increase knowledge on energy and emissions, land use, fresh water systems and coastal zones, and climate change, both with respect to the natural environment and social aspects.

Water is an essential natural resource for life on earth. Water sustains all life and regulates hydrological, ecological and chemical functions of ecosystems. Freshwater resources are a small component of the global hydrosphere and are subject to impacts of climate variation, anthropogenic climate change, human activities like land use (-change) and agricultural water use, technical water management measures, pollution etc. Both scarcity of good quality fresh water as well as excess water (floods) constitute increasing problems in many areas of the world. Water-related problems in developing countries are often related to lack of access to clean water, insufficient sanitation, absence of sound wastewater disposal, insufficient water for crops, disappearance of wetlands and the reduction of biodiversity. Water thus is a key to sustainable development, it is essential for human health and for ecosystem functions and it is a social and economic good.

Already for decades, water resources have a prominent position in the international policy framework. The 1970’s were declared the International Decade of Drinking Water and Sanitation. In Agenda 21 (Rio 1992), the WSSD (Johannesburg 2002, www.uneptie.org/wssd) and the 3rd World Water Forum (Kyoto 2003, www.world.water-forum3.com) many recommendations were adopted on research and policy on water resources, drinking water supply and sanitation.

The Earth Systems Science Partnership (IGBP, WCRP, IHDP and DIVERSITAS) has initiated the *Global Water Systems Project* (www.gwsp.org) . GWSP aims at strengthening and facilitating the wide array of current research activities that explore water issues. In addition, it aims at catalysing interdisciplinary understanding and synthesis of studies of components and processes in water cycles, including biological and biochemical aspects, human dimensions and socio-economic studies.

In the strategic plan of the NWO-Research Council on Earth and Life Sciences (ALW) the theme ‘Water’ aims at water systems at different spatial and temporal scales, such as the hydrological cycle as a whole, river systems and coastal zones.

The strategy of the NWO-Netherlands Foundation for the Advancement of Tropical Research (WOTRO) comprises the theme ‘Sustainable environment: biodiversity, energy and water’ which focuses on the “vulnerability and resilience of (sub)tropical natural and social systems to natural and anthropogenic changes at different time scales”. Subjects mentioned are a.o. impact of land-use on water regimes, sustainable use of water in agriculture and water use efficiency of crops, ecological effects of fresh water shortage, water distribution models, integration of ecological, social and economic research.

The NWO-Research Council for Social Sciences (MaGW) has included a theme Integrated Water Management in its new programme GAMON (deadline for pre-proposals 5 November 2003), focusing on human and societal aspects of the impact of climate change on water systems and of changes in water related policies in The Netherlands.

The Ministry of Spatial Planning, Housing and the Environment (VROM) has established a National Research Programme on Global Change. In this framework, funds for fundamental research were allocated to NWO. The Ministry has indicated specific issues of interest, among which ‘Vulnerability and Adaptation’ are of immediate relevance with regard to the above mentioned focuses on water.

The above considerations and objectives form the rationale to develop an interdisciplinary research programme on Water of which the scope and challenges are described in the following pages.

SCOPE AND CHALLENGES

Three complementary themes are distinguished:

1. *water and the earth system*
2. *global change and aquatic ecosystems*
3. *water and society*

Within the context of global change and in particular climate change, the scientific challenges of the programme relate to the following threads through all aspects:

- *diversity, heterogeneity, variability*
- *non-linearity, thresholds, boundaries*
- *vulnerability, resilience and adaptation (in The Netherlands, Europe and in developing countries).*

THEME 1. WATER AND THE EARTH SYSTEM

This theme comprises all research on the abiotic part of the earth's water system, including its links with biotic parts and human society. The theme is subdivided into five sub-themes. One sub-theme focuses on the complete water cycle and its relation with the climate system. Three sub-themes focus on parts of the water cycle, i.e. atmospheric water, surface water and subsurface water. A fifth sub-theme focuses on the role of water in terrestrial ecosystems. Hereafter, each of the sub-themes is introduced, major issues are identified and a number of examples are provided of research topics covered by these issues. For each sub-theme, research proposals are called for that pertain to the major issues identified.

1.1 The water cycle

The Water Cycle plays a central and integrative role in the dynamics of the Earth System**.** It is a key regulator of biogeophysical processes. Its physical state is closely linked to energy exchange within the global climate system. Water is essential to the maintenance of both terrestrial and aquatic ecosystems, providing habitat for aquatic species, many of which are important protein resources for humans. Through linkages with the carbon cycle, water and the water cycle help to regulate the release and sequestration of carbon dioxide, as well as other trace gases. The movement of water through the hydrological cycle comprises the largest flow of any material in the biosphere.

This sub-theme comprises all research on the water cycle as a whole, as well as its links to the earth's energy, carbon and nutrient cycles. Two major issues can be identified. The first deals with the question to what extent elements of the water cycle vary and change with time, and which internal mechanisms and external forcing factors (including human activities) are responsible for this variability and change. The second issue is concerned with feedback processes that control the interactions between the global water cycle and other parts of the climate system (e.g., carbon cycle, energy), and how these feedbacks are changing over time.

Examples of research topics that are covered by this sub-theme are: long term and inter-annual variability in runoff, soil moisture and groundwater storage, evaporation and rainfall, as well as effects of land use change and climate on these; observation and 4D-modeling methods to close the water cycle at various scales; coupled modeling of the water cycle and associated cycles (energy, carbon, nutrient); development of simple models expressing key features of feedback mechanisms to study the causes of resilience, hysteresis, abrupt change and chaotic behaviour.

1.2 Atmospheric water: Clouds, precipitation and land-atmosphere feedback

In the atmosphere, the hydrological cycle is manifest through the vertical and horizontal transport of moisture governed by large-scale advection, precipitation and surface evaporation. The representation of the hydrological cycle in large-scale models is hampered by insufficient treatment of a number of crucial components. This sub-theme will be aimed at strengthening our understanding and representation of two important components of the hydrological cycle. The first component requiring additional research is the interaction between precipitation, cloud formation and radiation. In the next years, an increased horizontal and vertical resolution in global and regional climate models is anticipated. The increased resolution will allow for a more precise treatment of local effects such as the link between the horizontal and vertical distribution of clouds and radiation, and the modelling of deep convection resulting in extremes of precipitation. Secondly, additional research is necessary to address the coupling between soil moisture, evapotranspiration, boundary layer transport and precipitation. Many modelling studies show a tendency to over-emphasise the positive feedback between soil moisture content, surface evaporation and precipitation, leading to dry and warm biases. The relative role of individual components interacting in this feedback cycle is still poorly known.

Examples of topics to be tackled in this sub-theme are: the development and validation of (sub)-grid parameterisations of clouds and precipitation; observations and modelling of precipitation variability, including radar hydrometeorology; experiments and process studies of the link between boundary layers clouds and aerosols; improvements to the coupling between soil moisture, evapotranspiration and precipitation; the development of cloud models at resolution of km scale including the transition in clouds to precipitation; the description of clouds and radiative distribution in terms of the horizontal and vertical variability of cloud water; sensitivity of the hydrological cycle at regional scale to feedbacks in the combined interaction between land/atmosphere, clouds/radiation, evaporation/boundary layer transport, and precipitation/evaporation.

1.3 Surface water

Surface water is the most visible part of the hydrological cycle. By far the largest part of human water consumption (70%) is obtained from surface water. Also, surface water related ecosystems such as lakes, wetlands and riparian areas are amongst the most diverse and valuable in the world. Moreover, fluxes of sediments, minerals and nutrients between continents and the oceans are mainly due to transport by rivers. Clearly, surface waters are the blood vessels of the continental part of the earth system.

This sub-theme focuses on quantifying the fluxes, stocks and residence time of surface water and its constituents in lakes, rivers and wetlands as well as surface water related sediment transport. Scales of interest may range from the hillslope scale to the scale of catchments, large river basins and continents. A number of large issues should be addressed. First, the quantification of stocks and fluxes at large scales requires the application of large-scale measurement technology such as gravity observations and remote sensing and the combination thereof with model predictions and ground based observations. This is even more pertinent in light of the deterioration and disappearance of ground based observation networks world wide. The IAHS initiative on Prediction in Ungauged Basins is a result of this concern. Second, apart from quantifying surface water stocks and fluxes, studies are called for that explore underlying mechanisms of runoff generation and sediment transport. Third, human impact studies are needed, i.e. concerning the effects of population growth, land use change and river regulation (e.g. dam building). Finally, research is needed that is concerned with the impact of climate change and the feedback mechanisms that may exist between surface waters and the climate system.

Examples of topics that will be tackled under this subtheme are: quantification of the surface water balance and the sediment balance (fluxes, stock and residence times) at various scales, including water and sediment related stocks and fluxes of minerals and nutrients; data-assimilation methods to combine model predictions and various types of observation data (remote sensing, ground based observations) to estimate surface water balance components; mechanisms of runoff generation; flood genesis and flood mitigation in headwaters and river valleys; prediction in ungauged basins; freshwater outflow to oceans (important due to its influence on the thermohaline circulation); nutrient cycling in lakes, rivers and wetlands; the relation between climate variability, runoff and river morphology.

1.4 Soil and groundwater

Subsurface water forms an important element of the hydrologic cycle. It harbours both abiotic (physical/chemical) and biotic (microbiological) systems that are intimately linked. Moreover, couplings with aquatic and terrestrial ecosystem exist due to the exchange of soil and groundwater with surface water and the atmosphere. Societal linkages are of paramount importance as man relies heavily on groundwater as a resource.

This sub-theme aims to address a number of major issues concerning sub-surface water. The first issue is heterogeneity and scale. The great temporal variability and spatial heterogeneity of soil and groundwater systems causes large uncertainty in system characterisation. Research efforts are needed that not only aim to quantify but also attempt to reduce uncertainty. A second related issue is the space-time variability of recharge and soil moisture. These components form the boundary conditions for groundwater systems and are strongly coupled to atmospheric processes. A third issue that is important and requires improved knowledge is the intricate and coupled hydrochemical and biological processes that control water quality in soil and groundwater systems. Finally, as a fourth issue, questions may be addressed as to the vulnerability and adaptation of soil and groundwater systems at various scales in the face of future climate change, changes in land use and urbanisation. Moreover, the role of groundwater in controlling surface water quality and quantity and, hence, surface water ecosystems may be explored.

Example topics under this sub-theme are: improved observation techniques and strategies that address the gap that often exists between measurement scale and model scale; study of the systematics of preferential flow paths in soils and confining units; scale issues in space-time soil moisture and recharge variation, in particular the spatial and temporal coupling with surface conditions (e.g. vegetation); redox-reactivity of aquifers, nutrient limitation and associated vulnerability of groundwater ecosystems; biogeochemical transport mechanisms in aquifers.

1.5 Terrestrial ecosystems and hydrology

Terrestrial ecosystems interact with elements of the water cycle in various ways. These interactions take place at timescales ranging from hours, through seasons to decades. The resilience of this coupled eco-hydrological system depends critically on the sensitivity and manner and magnitude of the coupling between water carrying components of the atmosphere, soil and vegetation. For instance, in certain ecosystems, the spatial redistribution of water and nutrients through plant induced differential infiltration and transpiration is considered as an important factor explaining the spatial distribution of plants.
The challenge is thus to address the question of how ecosystems interact with their environment to create sustainable boundary conditions for growth. It is important to better understand the constraints and possible feedbacks involved, as with a changing climate subtle changes in climate may generate major not only gradual changes but maybe also major unexpected shifts in ecosystem stability.

The relationships between water and other biogeochemical cycles are arguably one of the great other challenges for ecohydrology in the next decade. How does vegetation optimise the tradeoff between carbon uptake and water loss? Particularly in wetlands groundwater levels directly control the exchange of CO_2 (and trace gasses like CH_4 and N_2O). These links are poorly understood, and insight in these is required for management purposes and global change studies.

Examples of topics under this sub-theme are: mechanisms of vegetation pattern formation as explained from hydrological principles; feedback mechanisms, resilience and unexpected shifts in terrestrial ecosystems in the context of climate change; vegetation changes in wetlands resulting from climate change and human impact; strategies of individuals and terrestrial ecosystems as a whole to optimise nutrient uptake and water loss.

THEME 2. GLOBAL CHANGE AND AQUATIC ECOSYSTEMS

Climate change may have a tremendous impact on aquatic ecosystems. Climatic variables like precipitation, irradiance and wind are major drivers of ecological processes, through their effects on water temperature, hydrodynamics, water-column stratification and nutrient availability. Analysis of data from climatic gradients, palaeo reconstructions and recent time-series are essential, but also process oriented research is needed to allow better prediction of potential effects of climate change. On the other hand, aquatic ecosystems may also interfere with climate change, as they may store or release carbon and may also release other greenhouse gases such as methane and nitrous oxide. Further scientific advances in these areas are advocated.

Biodiversity is more threatened in freshwaters than in any other type of ecosystem. Also, freshwater of good quality is an increasingly scarce resource. Importantly, these problems seem tightly linked. Good water quality favours biodiversity, but biologically rich systems also seem to cope better with many pollutants. To understand the vulnerability of aquatic ecosystems to changes in climate, exploitation, pollution and other human pressures we need to enhance our insight in the mechanisms that govern the dynamics of aquatic ecosystems. A number of key issues deserve special attention.

2.1 Water quality and harmful algal blooms

Aquatic ecosystems have a '*self cleaning capacity*'. They may decompose numerous organic pollutants, reduce the activity of inorganic pollutants, and may remove excessive nitrogen loads through denitrification. How ecosystems affect the fates of chemical substances varies widely, depending on the pollutant concerned, and on the state of the ecosystem. Since humans have a large impact on the state of aquatic ecosystems, it is important to better understand this link between the state of aquatic ecosystems and their resilience.
Major threats to water quality and aquatic biodiversity quality are related to the development of phytoplankton blooms. Excessive growth of phytoplankton leads to turbid water, with a cascade of negative effects on aquatic plants, invertebrates, fish, and birds, as well as the deterioration of water quality for recreational use and drinking water. Over the last decade, the number of reports on harmful algal blooms has increased worldwide. Importantly, it is the specific species composition of the phytoplankton that often matters, because only a few phytoplankton species are highly toxic whereas many others are relatively harmless. Adequate prediction and management of these problems requires a better understanding of the conditions leading to particularly adverse phytoplankton communities.

2.2 Aquatic foodwebs and biodiversity

Although research has advanced our understanding of foodweb dynamics, insight in *multi-species interactions* is still in its infancy. This limits our understanding of, for instance, the effects of fisheries on multi-species communities. Also, much of the existing community theory is of limited use for understanding implications of *weather fluctuations and seasonality*. Another area of research is that of *stoichiometry* in aquatic ecosystems, i.e. to find out how elemental ratios regulate the abundance of key species and govern the transfer of energy and carbon. Finally, it is becoming increasingly clear that there is an exchange of information between predators and prey through *infochemicals*. Information transfer via infochemicals can be disrupted by pollutants.
Co-evolution is the force that shapes interactions between species, it allows species to specialise in their interaction with relevant other species only (e.g. predators, parasites, competitors). If we are really to understand the interactions between species that are so crucial to key processes in ecosystems we need to know more about the role of co-evolution. All these aspects of aquatic foodwebs deserve further attention, especially from studies that combine theoretical and empirical approaches.

Biodiversity of freshwaters is under pressure worldwide. It is important to improve our understanding of (i) the main *drivers* of aquatic biodiversity, and (ii) the implications of biodiversity changes for the *functioning* of aquatic ecosystems. For instance, does a loss of species imply that the system is more vulnerable to climate change or pollutants? A well-known stress to biodiversity is the invasion by *exotic organisms*. There is a need for better understanding of how invasive species interfere with the diversity and functioning of aquatic ecosystems.

2.3 Waterborne diseases

Local freshwater resources are vital for humans in tropical countries, but these same freshwater resources also carry the risk of disease. Examples of such waterborne diseases are bilharzia, giardia, and cholera. The population dynamics of these disease organisms, and the host species in their life cycles, are regulated by ecological processes. The tremendous 'biocomplexity' of disease problems implies that a multidisciplinary approach is our best hope of smart combat strategies. The link between aquatic ecology and epidemiology is one that merits further exploration.

THEME 3. WATER AND SOCIETY

Growing concerns over the finite nature of freshwater resources - occasioning scarcities, limited access and uncertain provision - are a reflection of increasing competition for water and the higher risk this brings for the livelihoods of poor households. Human activities affect the dynamics of global water systems in various ways. Inland water ecosystems are exposed to critical pressure due to competing claims and growing interdependencies. Water use patterns affect ecological resilience while emerging over-exploitation of water resources demand new initiatives to maintain or restore the integrity of the water cycle at different scales. Linkages of global water systems to the regional and local socio-economic context, in particular the vulnerability context of the livelihoods of the poor, need to be understood in order to identify new water management strategies that can deal appropriately with these dilemmas. Water scarcity can occur with diverse hydrological and social dynamics, in different freshwater sources, and the nature of problems and scope of monitoring and management systems need much further study. Global socio-economic forces play into shaping both regional and local scarcity and capabilities to negotiate new water allocation options.

To understand the interactions between water sources, water management regimes and technologies shaping water supply and allocation, we need to enhance insights in the processes and relations that shape mobilisation, distribution and use of water in society and the people's contestation over water resources. Therefore, the following key issues, which apply to developing and developed countries alike, deserve special attention:

3.1 Water scarcity, water governance and contestation over water

As water becomes scarcer, competition intensifies and its value rises. Given the widespread poverty in river and aquifer basins in developing countries, conflicts arise regarding the allocation of water between different social groups, activities and sectors. Scarcity not only refers to ' shortages of supply' but also reflects a social condition shaped by the institutions and power relations mediating spatial distribution, technical operation and temporal access to water. Culturally and conceptually, there are many different ways to see water as a resource, which also affect how people design new allocation models and tools. At the institutional level, water can be considered as a global commons, a resource amenable to private ownership or culturally connected to the land where it rises and is used, not merely as a means with which people make a living, but also give meaning to that person's world. Policies and technologies for water mobilisation and resource use face major dilemmas with population growth, demand uncertainties from transforming global markets, and alteration of the hydrological cycle and ecosystems.

Governance processes for managing uncertainty and vulnerability in the access of people to water include socio-technical systems for shaping knowledge, intervention and action. Negotiating access, managing hazards, and innovating production systems create scope for new governance practices/institutions. As global perspectives are brought into the water debate and pressures on water grow, the concerns over vulnerability, resilience and adaptation becomes embedded in wider debates that involve power relations, property rights and other, including spatial, interdependencies. Responsibilities for structuring access to freshwater resources are increasingly shared between public, private and voluntary agents.

These contemporary pressures emphasis the need to shift water management from a narrow engineering focus to one of social negotiation, but this is a far from easy process and requires first of all a grounded understanding of underlying social and political dynamics. Water management regimes are shaped by history and are often deeply embedded in (geo-)political and administrative structures. New debates around scarcity of water threaten the already deficient access of poorer households, bring contestation over new technologies for supplying water, new rules for allocating and managing them, or new regional or basin-level platforms for negotiation. At the same time, existing water institutions and policies are being reshaped by stakeholder platforms, advocacy groups, professional networks, and public private partnerships and state-NGO-civil society partnerships that offer new voices and ideas in negotiation.

Critical issues, questions and contemporary fields of study under this subtheme are: causes, conditions and approaches for understanding water scarcity; practices and processes in water resource management; co-evolution of access to water under different conditions of water availability ;transformations in institutions governing and negotiating water allocation systems, and their underlying power relations.

3.2 Water productivity, regenerative capacity and livelihoods around water uncertainty

Water is central to the production systems on which local and national economies depend, in many sectors of society. Economic development may cause major changes in the hydrological cycle and food chain (e.g. through irrigation, commercialised agriculture and drinking water provisions for cities). These transformations also cause environmental degradation such as salinity, pollution and declining soil fertility. Problems of imbalances in water flows and changes in hydrological cycles at various scales are strongly related to human intervention. Yet concepts and models for adequately portraying the decisions of actors regarding water use and environmental regeneration, and how these link with water dynamics, are scarce - especially in the context of poor people's livelihoods. Existing modelling of productive use of water cycles still focuses more on the profit and returns to land and water, rather than on optimal biomass production for livelihood security for all.

Existing evidence shows that the poor are often excluded from higher-value production options of water. The links between agricultural systems, water use and environmental change still needs further study, since concerns for an environmentally sound and ethically conscious agriculture are growing, while at the same time these concerns are sometimes criticised as further promoting hegemony of "western" values over the values of the poor.

Resilience and adaptation of water use regimes ask for innovations in production systems and should be confronted with improved understanding of coping and adaptation mechanisms in livelihood strategies. Actors not only cope and adapt to structural processes but transform them simultaneously. Water has great value also to local communities, both in its productive forms, for social security and as symbolic capital. Externalities of water systems and transboundary effects of water management ask for conservation and water management initiatives that could restore environmental quality.

Critical issues, questions and contemporary fields of study are: transformation of water management in production systems and livelihoods, and for ecological resilience; alternative regimes for assessing water productivity, and pricing and valuing water and environmental services; conceptual and methodological approaches to studying linkages between the water cycle, water use practices, and ecological integrity; dealing with water uncertainties through adaptive livelihoods and cultural practices.

3.3 Water management, water networks and control of floods and water supply

Institutions and technologies interact regarding the mobilisation, distribution, supply and control of water resources for human needs, and they shape and are shaped by the water cycle. Water delivery systems and their operational management involve technical, organisational and often political control, that can be studied through the agency of 'water networks'. While water networks are designed in relation to water supply, they must also cope with variability and change in climate and extreme events at different levels of their operations, including flood, drought and changes in water quality.

Technology choices for improving water use efficiency include both physical infrastructure for mobilisation and delivery, and other relevant production technologies. The 'expert systems' and knowledge claims involved in their management shape abilities to reform management and operations, and act at times of crisis, but increasingly must do this together with users. Adequate interfaces between water systems and the human skills, structures and resources for their management are critical for societies to deal with contemporary water problems.

As new water management and allocation regimes are emerging with the evolution of society, local practices in operations of socio-technical systems often struggle for change. However, local action is also dynamic, adapting to and challenging new policies and guidelines, and developing new practices. The interaction and struggle of micro and macro actors over water claims, and their actions around technology, can lead to new understanding on the impact of governance regimes and water movements on freshwater dynamics. Regarding the management of water resources, interaction between the water system and the socio-economic system is of importance. Changing the manner of water management, sometimes institutionalised for centuries, in order to cope with climate change (more floods and droughts), requires taking account of stakeholders with conflicting interest. Also, the public and political consensus on water management, i.e. world view (egalitarian, hierarchic,) and associated management styles, is dependent on socio-economic and climatic fluctuations and may suddenly change due to extreme events. For instance, in the Netherlands the floods of 1995 and 1998 have changed the style of water management from fighting and controlling water to accommodating water in more natural functioning water systems. Given the expected changes in climate and possible impacts on the water system, there is a need for long term strategies that are robust against uncertainties in socio-economic and climatic fluctuations, yielding acceptable solutions for all stakeholders. Identifying such strategies requires the coupled modelling of the water and the socio-economic and socio-political system and the definition of realistic and complete perspectives and story-lines.

Critical issues, questions and contemporary fields of study are:
management of water systems and the realities of water delivery and flood mitigation at times of extreme hydrological events; transformation of system operations under changing hydrological and management regimes and globalisation forces; influences of hydraulic technologies and local management on water use practices and water use efficiencies; bargaining frameworks for resolving competing water claims by different actors at various scales; what are robust long term water management strategies given uncertainties in climate and socio-economic fluctuations.

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