The Challenge Program "Water and Food" for river basin scale water resources assessment

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Abstract: A key component of the Green Revolution was the investment of many billions of dollars in irrigation infrastructure. This progress was accompanied by populations rise, and countries industrialization. The latter created a substantial demand for water in urban areas of developing countries, and will increase significantly in the coming decades. Large-scale development of river and groundwater resources, however, is less acceptable and less cost effective now than it was in the 1960-1990 period, when most of the world's 45,000 large dams were built. Irrigation agriculture is consuming a large share of available water resources but other water user sectors are claiming their demand as well. Groundwater resources are drying up and the willingness to develop new resources has declined for financial as well as environmental reasons. To assess innovative methods of Integrated Water Resources Management (IWRM) and water productivity in irrigation agriculture but preserving environmental sustainability the Challenge Program "Water and Food" has been launched by the CGIAR in November 2002. Applying 'frontier science' to produce more food with less water, the program will integrate cutting edge science and research knowledge, including functional genomics and molecular biology; the use of remote sensing and GIS tools; and global modeling linked to the global change research projects. The paper presents the research organization structure and potential of the research program and its key components.

Keywords: *Integrated water resources management (IWRM); Water productivity; Multi-scale water resources assessment; River basin information; Hydrological Response Units; Modelling*

1. INTRODUCTION

The Green Revolution in the past consumed billions of dollars invested in irrigation infrastructure also established under-performing irrigation schemes and caused heavy social and environmental costs not always accounted for. Although believed to be a major driver for poverty alleviation and improved livelihoods the overall benefit of the Green Revolution is still subject for discussion.

Population growth, rise of incomes, and countries industrialization creates additional demand for water in urban areas of developing countries which will become an increasing priority factor in the forthcoming years and decades. The majority of water related services globally are provided by glaciers, snow covered mountains, lakes, rivers, wetlands and marine waters (COSTANZA et al. 1997). In their regional assembly and sum they comprise the natural river basin water potential in which water management and economic development takes place.

These services are depending on a management strategy which must account for criteria of sustainability and basic principles of system's balancing. In the contents of the river basin the latter, however, are not always implemented very well or are neglected in a shortsighted view: i.e. groundwater aquifers are overexploited, reservoirs are silting up due to heavy erosion in the basin, and irrigation networks are badly maintained.

1.1 Irrigation Agriculture

In semi arid areas of the world irrigation agriculture is the main water consumer. With increasing growth of population and ongoing industrialization other economic sectors such as hydro-power, industry and expanding urban areas are claiming an increasing share of this scarce natural resource. The development of irrigation agriculture in the past was based on receiving cheap and sufficient water for producing food for a population which tripled in the twentieth century. Due to major investments in water resources infrastructure and mostly uncontrolled and subsidized pumping of groundwater in the last decades water use for irrigation multiplied almost six-fold. This was accompanied by a sharp rise of agricultural productivity due to higher yielding crop varieties and increased fertilizer use.

It is understood that such a productivity trend cannot be taken for given and extrapolated into the future, as **(i)** in many regions of the world the available water resources have already been allocated to a vast extend, **(ii)** other water demands from economic powerful stakeholders must be fulfilled, and **(iii)** the anticipated global climatic change might impose an even stronger stress towards the already unbalanced water consumption in these regions.

1.2 Rainfed Agriculture

Water management practices, such as water harvesting in rainfed agriculture have important implications for food security and alleviation of poverty on the one side, and environmental sustainability on the other side. Improving the productivity of rainfed agriculture, water harvesting and supplemental irrigation are likely to reduce the need for irrigation extension thereby reducing the pressure on scare water resources.

However, research in dryland and irrigation related salinity (FLÜGEL, 1995) revealed that rainfed as well as irrigation agriculture both require a sophisticated "on farm" water management to avoid degrading processes to take over. The spectrum of water use for agriculture must consequently comprise options from fully irrigated, to rainfed, and choices in between, such as supplemental irrigation and the use of small rainwater harvesting structures.

1.3 Integration of Water Quality

As water use intensifies, water quality becomes more of a concern. High agricultural production is impossible without the use of fertilizers and the chemical protection against diseases and pests. Remainders of these chemicals are leached and transported into underground and surface water resources. In addition industrial and urban waste waters are frequently insufficiently processed and directly discharged from the sewerage system into the river or ocean. Aquatic ecosystems are consequently affected or even destroyed by polluted discharges from agricultural and non-agricultural uses.

Due to pressing water shortages irrigators in the vicinity of urban settlements rely on untreated city effluents for the supply of water and as a source of nutrients for their crops. This causes short term and long term health problems due to the load of E-coli and heavy metals imported by such water to the irrigated fields and crops.

For many rural people, agricultural water is the main source of drinking water, a benefit when the water is clean, but a health risk for millions if they have to drink water contaminated with E-coli bacteria, arsenic or fluoride. The health and environmental factors of water use are not well known, but yet essential in any strategy for sustainable water use.

1.4 Future Challenge

In conclusion of the preceding overview the forthcoming challenges for Integrated Water Resources Management (IWRM) in relation to agriculture and within the context of river basins can be setup as follows: **(1)** The growing population has to be supplied with sufficient food and water as a basic requirement to alleviate poverty and improve livelihood of the poor. **(2)** Irrigation agriculture received large financial investments and subsidies not likely to be repeated in forthcoming decades. **(3)** Water diversion to irrigation agriculture will be under increasing stress and face competition with demanded shares claimed by other powerful water users. **(4)** The necessity to reserve water to sustain the environment is worldwide recognized and will become a further priority factor for basin water management.

This setup requires a combined research effort of all disciplines involved focusing on the major challenge: To produce more food with likely less available water, and thereby meeting other economic needs and environmental demands.

2. THE CGIAR CHALLENGE PROGRAM (CP) "WATER AND FOOD"

The Consultative Group of International Agricultural Research (CGIAR) addresses this challenge with the Challenge Program (CP) „Water and Food", which focuses on the paradigm to divert sufficient water for growing food and simultaneously satisfy demands of other important water users. The program's inception phase has been launched in November 2002, and the CP is designed as a research and capacity building program to run for a period of ten to fifteen years comprising two to three five year project periods.

It is expected that the investment in the CP „Water and Food" will indirectly or directly attract considerable additional funds, so that the research agenda developed through the CP will make a significant contribution to the agenda that drives research in the water and food community in the developing world and globally.

2.1 General and Specific Objectives

The general objective of the CP Water and Food addresses the global challenge specified above: The demand for an increase of food production to supply a growing population but maintaining the level of present use of water for agriculture and thereby stimulate and support industrial and urban development. With this objective the CP „Water and Food" is significantly contributing to achieve internationally adopted targets set by the year 2015 for river basins with natural, economic or environmental water scarcity such as to:

- decrease malnourishment and increase health,
- alleviate poverty in rural and peri-urban areas, and thereby
- improve and stimulate economic development in regions of the river basin with low average incomes.

The general objective will be achieved by the following **specific objectives** to be elaborated in applied and basic research projects and describing the four key dimensions in which progress towards the general objective can be assessed:

(i) Establish improved *food security* at household level.

(ii) Contribute to *poverty alleviation*, through increased sustainable livelihoods in rural and peri-urban areas.

(iii) *Improved health*, through better nutrition, lower agriculture-related pollution and reduced water-related diseases.

(iv) *Environmental security* through improved water quality as well as the maintenance of water related ecosystem services, including biodiversity.

3. THEMATIC AND GEOGRAPHIC FOCUS

The CP "Water and Food" has adopted a matrix approach that provides thematic focus by five research themes within a set of selected river basins. This strategy is important to achieve the required integration of diverse scientific disciplines related to the general objective. They will not only provide methodical knowledge from applied research but will also reveal the generic components of the studied process dynamic.. The geographical dimension establishes the linkage to the "real world" diversity of the food problem the CP "Water and Food" is contributing to.

Research projects approved for funding by the CP must fit into this thematic-geographical matrix by addressing either research issues of multiple themes in one river basin or alternatively will work within one theme across various river basins.

3.1 Research Themes

The CP "Water and Food" is conceptually structured in five interlinked key subsystems which are organized within three hierarchical scale levels:

- The micro-scale level comprises the process systems describing the *plant-field-farm-system* level. At this level three of the five research themes are active: ***Theme 1***: *Crop Water Productivity Improvement*; ***Theme 2***: *Multiple Use of Upper Catchments* and ***Theme 3***: *Aquatic Ecosystems and Fisheries*.
- The meso-scale level is represented by the *river basin*. At the basin scale ***Theme 4***, *Integrated Basin Water Management Systems*, investigates strategies of water allocation supplying the different water users from agriculture, urban areas, industry, and environment with their water share. Special focus is given on **(i)** the availability and quality of water from different sources such as surface water, groundwater and precipitation, and **(ii)** the interactions and trade-offs among and across water consumers.
- The macro-scale is the *external environment* in which the river basin is situated. On the scale, which comprises the national and global environment ***Theme 5:*** *Global and National Food and Water System* focuses **(i)** on the water sector in relation to global circulation dynamics and anticipated global climate change, and **(ii)** on macro-economic policy that impact the water sector such as trade in food and fiber, or energy policies.

3.2 Benchmark Basins

The geographic focus of the CP also considers the representation of the different regions important to the work of the CGIAR, and is provided by the CP Benchmark Basins (BB). The latter provide the research laboratory for the five themes to work in. They have a global dimension in their geographic distribution and provide a representative assembly of the "real world" water allocation problems the Challenge Program is committed to achieve significant impacts. In addition the basins need to be relatively large to study upstream-downstream relations as well as institutional and policy issues.

Altogether seven BBs and two "Associated Basins (AB)" have been selected so far but can grow in number and scope. The BBs are: **(1)** Yellow River (E-Asia), **(2)** Mekong River (SE-Asia), **(3)** Indus-Gangetic Systsem (Asia), **(4)** Karkeh River (W-Asia), **(5)** Limpopo River (S-Africa), **(6)** Nile River (E-N-Africa), **(7)** Sao Francisco (S-America). The two AB are: **(1)** the Volta River (W-Africa) and **(2)** several Andean Rivers (S-America and M-America).

River basins stretching over different climatic zones such as the Yellow River or the Nile River have been chosen by purpose and in support of the CP research matrix described above. They permit to study and simulate process dynamics interactive on different scales and various levels across geographical regions. It is foreseen that research projects will establish a number of pilot study areas on a micro- and meso-scale level representing the natural and socio-economic heterogeneity of the respective BB.

Research activities in each BB of the CP "Water and Food" will be guided and advised by Benchmark Basin Coordinators, represented by strong NARES (National Agricultural Research Service). They are responsible for the stakeholder group process, development of benchmark basin research priorities and baselines, data acquisition and modeling framework and a general research platform for their benchmark basin. They will also coordinate the synthesis of research results and other innovations developed through the CP for their basin.

4. RELATION TO GLOBAL RESEARCH

There is a distinct global perspective and dimension of the CP "Water and Food" that can be seen in its general objective, its conceptual design and its thematic-geographical research matrix. As the CP has adopted the principle of integrated systems analysis and is carrying research of interactive process dynamics across scales it consequently will also significantly support and contribute to the global research agenda.

As the quality of water related ecosystem services specified above controls the development and sustainability of human life by providing food and permitting the use of natural resources, global water dynamics are of significant relevance for the long term integrated water management strategies within river basins as targeted by the CP.

Climate change induced by increasing concentrations of greenhouse gases, especially carbon dioxide (CO_2) will trigger consequent adaptations of ecosystems and their service capacity for human development. It is likely that the benchmark basins selected by the CP, and under serious water stress at present, will not receive significant relief from such a change in the future.

It is common understanding that climate change will have consequent impacts on global water cycles, which in turn will have significant affects on river basin water balances. The natural water supply of the selected CP benchmark basins is already under risk due to a high variability of rainfall in time and space. It is likely that this situation will deteriorate as a consequence of climate change. Future water management strategies must therefore account for such "what-if?" scenarios and thus are a priority issue of the CP "Water and Food". Such scenarios include beside others

- a change of rainfall pattern in time and space,
- shorter growing seasons,
- changing moisture regimes and
- hazardous weather extremes such as floods and droughts causing consequent effects on social and economic systems.

Spatial analysis of hydrological water balances and regional hydrological models for integrated water resources management (IWRM) on the basin scale consequently have to link with related global scale research including:

(i) Selection and test of appropriate regional hydrological simulation models and their process algorithms for IWRM.

(ii) Application of a generic, process oriented regionalisation concept integrating dominant components of the natural and human environment for delineating model entities for hydrological process algorithms.

(iii) Remote sensing approaches for geo-spatial classification, model parameterization and validation.

(iv) Design of an object oriented modeling framework systems (OMFS) providing a common platform to accommodate these simulation models.

(v) Distributed geo-spatial database systems interfaced with the OMFS for IWRM and decision support.

4.1 Hydrological Simulation Models

There is an extensive literature about regional hydrological simulation models, describing their underlying regionalization concept and application potential the CP can refer to (SINGH, 1995), However, the number reduces considerably if a fully distributed regionalization concept and an object oriented software design is demanded.

Models such as PRMS/MMS (LEAVESLEY, 1983) and J2000 (KRAUSE, 2001) are fulfilling these criteria, others like SWAT (NEITSCH ET AL., 2000) only to some degree. They have, however in common to rely on well researched process algorithms which have been developed for the field micro-scale or the river basin meso-scale. The literature about global hydrological models is less extensive although models such as WaterGAP (DÖLL ET AL., 1998) have been described in some detail.

The challenge which will be dealt within the CP "Water and Food" research is to link the hydrological and climate model tools in such a way that their simulation output is complement model input of the next higher or lower scale hierarchy.

4.2 Regionalization Concept

The development of sound regionalization concepts proceeded from lumped (basin is one unit) to fully distributed (basin consists of several connected units), and evolved hand in hand with the development of hydrological water balance models. . Distributed models apply spatial process entities spread over the basin either as geometric grid cells or as Hydrological Response Units (HRU) i.e. defined by FLÜGEL (1996). HRUs are identified according to process based criteria accounting for the components of the natural and human environment. They are delineated by means of sophisticated GIS analysis (FLÜGEL, 1997) and networked via their topographic topology (STAUDENRAUSCH, 2001).

The HRU approach has been applied successfully in various climatic and topographic regions in Europe, the US and Africa (FLÜGEL and LÜLLWITZ, 1993; FLÜGEL, 1996; KRAUSE, 2001; STAUDENRAUSCH and FLÜGEL, 2001) and offers potential for interdisciplinary application (FLÜGEL, 2000).

4.3 Remote Sensing Application

The application of remote sensing for geo-spatial analysis, in agriculture and hydrology has boosted in the past and will likely continue to do so in the future (ENGMAN and SCHULZE, 2000). The potential of these techniques for model parameterization and validation, as well as for the delineation of HRU has been investigated extensively by the EU-project ***ARSGISIP*** (FLÜGEL, et al., 1999; MÜSCHEN et al., 2000).

The multi-scale resolution in time and space, and the application of physical measurements for distributed spatial analysis strongly recommend this technique for research in the CP "Water and Food" to classify the distribution of topography, land cover, soil moisture, rainfall input and evapotranspiration

4.4 Remote Sensing Application Object Modeling Framework System (OMFS)

As can be seen from the discussion above the thematic-geographical research matrix of the CP comprises various disciplines contributing to the common general and specific objectives of the program. Each of them runs its individual research agenda and applies different types of simulation models ranging from statistical regression to physical based and physio-chemical process models.

Integration of these simulations in the sense of an holistic systems analysis requires the methodical combination of scientific approaches represented in their respective simulation modules. This challenge is conceptual "frontier research" and requires a software platform which supports such integration. Object Oriented Design (OOD) provides the means and has been applied in this regard. The Object Model System (OMS) briefly described by DAVID et al., (1997) is an example for such a system providing these framework capabilities. It is expected that research projects in the CP "Water and Food" will embark on this technology to promote the conceptual integration of their models into a holistic multi-scale systems design.

4.5 Integrated Data Information System (IDIS)

Improved strategies of IWRM – one of the CP key objectives – requires decision making based on reliable data and model simulation (DAVID ET AL. 1997), stored and easy accessible in an Integrated Data Information System (IDIS). By means of the Unified Modelling Language (UML) the IDIS of the CP is designed in the following packages providing means to store the scientific knowledge and data expected from the various CP research projects:

(i) River Basin Information System (RBIS) comprising information about the natural and human environment of the river basin.

(ii) Model Information System (MIS) providing metadata about models available to the CP "Water and Food".

(iii) Data Information System (DIS) containing metadata about times series and their respective data.

(iv) Data Derived Evaluation (DDE) containing scientific knowledge derived from published data evaluation together with indicators classifying the spatial heterogeneity within the basin.

By its conceptual structure IDIS also provides potential for an extension towards a knowledge based comprehensive Decision Support System (DSS) which then will be linked towards the simulation models residing within the OMFS.

IDIS is completely based on the open source software components PostgreSQL, PostGIS, Minnesota Map Server (MMS) and Apache Webserver and will be installed within the domain of the CP at each BB coordinator office. Update and backup will be handled by a Data Base Network System (DBNS) developed by the Department of Geoinformatics at the University of Jena, Germany (http://www.geogr.uni-jena.de), and all software developments will be made public available.

5. CONCLUSION

Population growth, rise of incomes, and countries industrialization creates additional demand for water in urban areas of developing countries. To satisfy these demands water has to be diverted from agriculture to these water users and will increase the already existing deficits for irrigated food production. It is likely that this competition will exaggerate in the forthcoming years due to the negative impacts from global climate change.

The CGIAR has recognized this problem and in response in November 2002 launched the Challenge Program "Water and Food". The multimillion dollar research program will be carried out in different river basins distributed globally and focusing on research subjects as defined in five key themes of the CP.

The research is expected to contribute towards a holistic systems analysis and understanding which will promote the design of policies improving the development of management strategies to increase food production but keeping the water consume for agriculture on the present level.

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