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GLOWA

German Programme on Global Change in the Hydrological Cycle

(Phase I, 2000 - 2003)

Status Report 2002

ENVIRONMENTAL RESEARCH PROGRAMME

This report produced on behalf of the BMBF is supposed to present the results of the first period (2000-2002) of the German Programme on Global Change in the Hydrological Cycle (GLOWA).

The respective research-groups are responsible for the content of their papers.

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Projektträger des BMBF für
Umwelt- und Klimaforschung

Kühbachstr. 11
D-81543 München
Tel.: (089) 651088-51
Fax: (089) 651088-54
Email: pt-ukf@gsf.de
WWW: www.gsf.de/ptukf

Table of Contents

German Programme on Global Change in the Hydrological Cycle
(Phase I, 2000-2003) Funded by BMBF

Status Report 2002

GLOWA-DANUBE

GLOWA- IMPETUS

GLOWA- VOLTA

Introduction to the Programme GLOWA

GLOWA – an example of integrative, interdisciplinary and application-oriented global change research

Martin Rieland, **Federal Ministry of Education and Research, Division 422**
Postfach, 53170 Bonn

1. Introduction

Research in the area of global change is done with the objective of revealing to politics, industry and society the causes of observed global pattern changes and the interactions involved, the extent to which natural variability of global environmental phenomena is influenced by humankind, the extent to which changes can be forecasted and the implications of these changes for social systems, in particular with regard to the aim of sustainable development. Global environmental changes, such as changes in the chemical composition of the atmosphere, the climate or the biosphere, show regionally varying patterns. They have to be related to very specific social sensitivity patterns in different regions and therefore also entail specific regional adaptation and reduction options. Therefore Global environmental changes show highly complex, regionally varying and mainly long-term cause-effect structures which are linked to special demands on research methodology and tools as well as on early-warning and planning tools. This situation was pointed out in Germany for the first time by the German Advisory Council on Global Change of the Federal Government in its 1996 annual report 1996 "World in Transition: The Research Challenge". The issue was discussed and thematically further focused by the National Committee on Global Change Research (NKGCF) of the DFG and by the bodies of the Federal Ministry of Education and Research (BMBF). This process led to the establishment of the BMBF programme GLOWA (Global Change in the Hydrological Cycle) as a major approach in Germany towards the realisation of integrative, interdisciplinary and application-oriented global change research.

2. The BMBF programme GLOWA

The medium- and long-term availability of water is not only called into question by a continually growing world population and partly excessive use of water as resources but is also increasingly influenced by global environmental changes. The aim of GLOWA is the development of strategies for sustainable and future-oriented water management on a regional level while taking into account global environmental changes and socio-economic framework conditions. The programmatic orientation of GLOWA focuses on case studies for large river catchment areas (i.e. some 100,000 km²), where simultaneous research is done in a collaborative research programme on interrelations between changes in the hydrological cycle and

- the large-scale climate and precipitation variability,
- changes in the biosphere (in particular caused by changes in land use) as well as
- the effects on water availability and related conflicts of use.

The BMBF announced GLOWA on December 10, 1998. The following 4 GLOWA projects were launched in 2000:

- IMPETUS
  (Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa): case studies in the catchment areas of the rivers Drâa (Morocco) and Ouémé (Benin)

- GLOWA – Volta
  Sustainable management of water resources: intensive land use, precipitation variability and water need in the Volta basin: case study in Ghana and Burkina Faso.

- GLOWA – Elbe
  Integrated analysis of the impact of global change on environment and society in the Elbe area

- GLOWA – Danube
  Integrative techniques, scenarios and strategies concerning global change of the hydrological cycle of the catchment area of the upper Danube

The final goal of these GLOWA projects is to develop simulation tools which can be used for preparing and supporting decision – making. A GLOWA project combines up to some 15, natural and socio-economic scientific disciplines to set up such a simulation tool. The methodology for the integration has not been prescribed. Each GLOWA project realises its own integrated approach which depends on the specific circumstances (e.g. availability of data and models, depths of contribution / co-operation of stakeholders) in the area of investigation.

The BMBF supports these projects over an initial period of three years, which may be extended for up to eight years. The current support budget of the BMBF is some DM 13 million per year. Under these GLOWA projects, integrative competence centres in the area of global change research are being developed at some universities, relevant activities are co-ordinated and supported by the universities and the German *Länder* concerned (20% of total costs). For additional information see http://www.glowa.org/

Outlook

Global change issues should be adequately dealt with only if research, which is currently still mainly discipline-oriented, is extended to include an integrative, interdisciplinary point of view with a sufficient degree of abstraction. Such an approach must be oriented towards the overall system and focused on the complex interactions between natural and social systems. In the context of water and similar to GLOWA there are now new international programmes and initiatives on their way, such as the Joint Water Project by IGBP, WCRP and IHDP or the new HELP (Hydrology for the Environment, Life and Policy) programme within the oncoming 6th International Hydrological Programme of UNESCO, which aim to achieve this higher degree of co-operation, integration and interfaces between seemingly incompatible disciplinary research approaches.

Thus, Global change research is at the beginning of a learning process in which the plurality of methodological approaches in integrated and interdisciplinary research is decisive. It is obvious, that there is the need to have intensive exchanges of knowledge and experiences between these different initiatives. The learning process will take time. We need to go further step by step while concentrating on concrete questions and applications. The crucial and still open question for this approach is that of the applicability of the results. Global environmental changes alter the future living conditions of people. It must be demonstrated that Global Change research is able to give answers which will allow decision – makers to actively shape global change in a future-oriented and sustainable way.

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GLOWA-Elbe

INTEGRATED ANALYSIS OF THE IMPACTS OF GLOBAL CHANGE ON THE ENVIRONMENT AND SOCIETY IN THE ELBE RIVER BASIN

A. Becker[1], F. Messner[2] and V. Wenzel[1]

[1] Potsdam Institute for Climate Impact Research (PIK), Telegrafenberg C4, 14473 Potsdam (alfred.becker@pik-potsdam.de; http://www.pik-potsdam.de)
[2] Centre for Environmental Research (UFZ) Leipzig-Halle, Permoserstr. 15, 04318 Leipzig (messner@alok.ufz.de; http://www.ufz.de)

Keywords: Integration approach, ecosystems, socio-economy, sustainable development, Global Change, impact assessment, Elbe river basin, water management, water balance

Abstract

To analyse and understand the impacts of Global Change (climate and socio-economic changes) at regional scales a new interdisciplinary Integration Approach has been developed, which involves stakeholders to the largest possible extent. It is applied in the subprojects (SP) of GLOWA-Elbe, in the most comprehensive form and with new methodological developments in the Spree/Havel tributary river basin. The general aim is to develop methods and advanced modelling techniques and tools, which can be applied for providing decision support in solving the given problems in water availability and quality and the resulting conflicts in water allocation.

Water related problems and conflicts in the Elbe river basin

The Elbe river basin in Central Europe with a basin area of nearly 150,000 km^2 (about 2/3 of it in eastern Germany, 1/3 in the Czech Republic) covers middle mountain ranges in the south and west (Czech Republic and adjacent German Erzgebirge north to it, Thuringian Forest, Harz and some other mountain ranges) and large, relatively dry flatlands and lowlands in the rest of the basin (central, northern and eastern German parts). The basin is characterized by a variety of environmental and socio-economic conditions and in some parts rather complex problems and conflicts due to water availability and quality limitations. This concerns in particular the Spree/Havel river basin (24.000 km^2 in area) with extended open pit lignite mining activities and associated problems in the upper Spree river basin in Lausatia (subproject (SP) 2.1), which have consequences for several downstream parts of the river basin, especially for the "Spreewald"-region (SP 2.2), a typical riverine wetland and internationally accepted biosphere reserve, and the lower Spree river basin with the developing urbanized region of the German capital Berlin as well as the lower Havel river down to its confluence with the Elbe river (SP 2.3).
All water availability problems and water use conflicts in the Elbe river basin must be considered in the context of the German reunification in 1990 and the resulting changes in the political and economic conditions, which in several cases amplified the existing problems and user conflicts. The most critical example is Lausatia (SP 2.1) where the abrupt reduction of mining activities resulted in associated reductions in water availability and quality, due to missing releases of groundwater pumped earlier from the open pit mines into the river system, and to the acidification of groundwater when it re-rises in the former mining areas and

consequently fills the lakes in the open pit mines with acid water. To avoid or mitigate this development freshwater is needed, which at present is simply not available in the region.
The other three subprojects (SP) in GLOWA-Elbe are concerned with the entire Elbe basin (SP 1), the Unstrut river basin in the mountain forelands of Thuringia (SP 3) and the development of future climate scenarios (SP 4).
The principal objective of the project is to analyse the above and other developments in the context of Global Change and to develop methods and tools capable of providing decision support for the derivation of strategies, measures and action programs towards problem solution and aiming in the end at a sustainable development of the Elbe river basin.

Participation based "GLOWA –Elbe Integration Approach" and implementation of it in "nested" studies within the Elbe river basin

To fulfill the above task a new approach has been developed to integrate various science disciplines in regional river basin related studies (interdisciplinary integration) and to achieve a transdisciplinary integration in terms of the active participation of policy and decision makers, actors and stakeholders in the widest sense (land owners, environmentalists, interest groups). According to Fig. 1 the approach includes four main steps (Wenzel 2001):
- DEVELOPMENT of a catalogue OF SCENARIOS of change considering on the one hand expected changes in climate, economic, demographic and social development and on the other hand possible measures for action,
- Identification or definition of INDICATORS OF SUSTAINABILITY AND OF RELATED CRITERIA for the evaluation of results of scenario analyses,
- ANALYSIS OF the IMPACTS resulting from the defined scenarios of development using available data, models, expert knowledge and relevant literature,

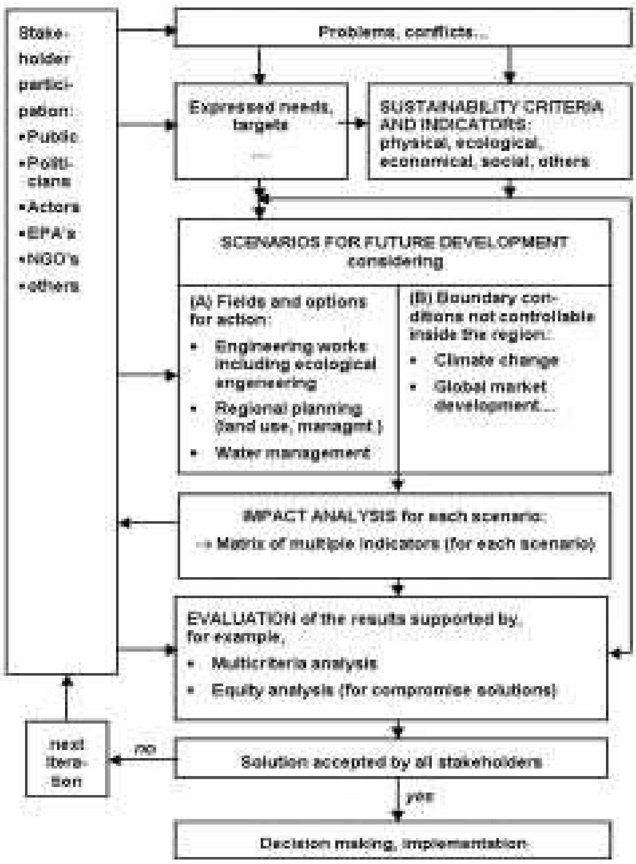

Fig. 1: The GLOWA-Elbe Integratzion Approach

- EVALUATION of the results of the analysis with support of advanced techniques such as multicriteria analysis to determine, in consultation with actors, politicians and stakeholders, appropriate (optimum or at least acceptable) strategies and measures of action, which ensure or at least support the solution of problems and conflicts and contribute to sustainable development.
Participation as essential feature of the approach is illustrated by the arrows out of and into the left block in Fig. 1.
Based on earlier developments (Becker 1998) the approach is applied in GLOWA-Elbe in so-called "nested" studies at two spatial scales (domains):
(i) at the scale of the entire basin (SP 1 and 4). These studies are focussed on the development of climate change scenarios for the coming 50 years (SP 4), the estimation of the influence of

global food market developments on agriculture in Germany, and the development of data base systems, methods and tools required for the basin wide analysis (SP 1).
(ii) At the scale of selected tributary river basins where special problems and conflicts occur and need to be solved, required data are available, and actors and stakeholders are willing or even interested to actively participate in the application of the GLOWA-Elbe Integration Approach (SP's 2.1, 2.2, 2.3 and 3). These studies represent "nested" integrative studies where the four steps of the Integration Approach are applied as far as possible.

Innovation steps and first results of GLOWA–Elbe

After two years of research in GLOWA-Elbe the following results have been achieved:
1) A new participation-based interdisciplinary integration approach (GLOWA-Elbe Integration Approach) has been developed which is now applied in all regional subprojects of GLOWA-Elbe with region or task specific differentiations. The approach has been presented to the international science community in November 2001 in the International Symposium on Ecological Engineering, where it was appreciated as generally applicable and future oriented. In a workshop on Decision-Making it was discussed by an expert group, in parts further developed and finally labelled as "NON-ROUTINE DECISION MAKING PROCESS: Structural scheme towards a general approach" (Peet 2001).
2) A special working group on Scenario Development was established in GLOWA-Elbe, which after extensive discussion defined the principles, a unified procedure, general criteria and the boundary conditions for the scenario analyses in GLOWA-Elbe. They are now applied in all subprojects in a coordinated way so that the results can be intercompared, generalised and used for upscaling.
3) Straight forward approaches are applied to downscale important "boundary conditions" for the various impact studies in the Elbe river basin, namely future climate and global socio-economic developments:

(a) a combination of the dynamical climate models ECHAM/OPYC3 (global) and REMO (regional), developed and implemented at the MPI Hamburg and supplemented by special validation and scenario development procedures of the FU Berlin,
(b) a statistical model based on a special cluster analysis algorithm developed at PIK for the generation of numerous realisations of future regional climate scenarios referring to global climate simulations (e.g. ECHAM),
(c) the partial equilibrium model WATSIM in combination with RAUMIS to prescribe expected future developments of the global agricultural commodities market and the resulting regional development of agricultural production at district scales in the Elbe region.

4) These approaches are now applied and the following results have already been provided:
- 100 different realisations of future climate in the Elbe region over the coming 50 years (2001-2055) (approach 3b) referring to a climate change scenario simulated by ECHAM with emission scenario A1 of the IPCC. These are now used as input for the simulation of water resources availability and management in the Spree/Havel river basin pilot study (SP 2). It is the first time that such data sets are available for hydrological and water management studies allowing the analysis of risks in terms of probabilities of exceedence of predefined levels (thresholds) of streamflow or groundwater level (e.g. low flows, flood flows), deficiencies in water supply, and other hydrological and related environmental and socio-economic characteristics.
- Agricultural development scenarios at the scale of districts (approach 3c). These are used as input for the basin wide spatially distributed, hydrotope and district related analysis of impacts on the water and nutrient balance and on agricultural production (crop yield). First results were already achieved in a pilot study for the state of Brandenburg (SP 1).

5) A long-term hydrological and water management model ArcGRM-GLOWA was developed and is now applied in a basin wide pilot study in the Spree/Havel river basin (SP 2) to analyse and understand the impacts of Global Change direct human activities in the region on water resources availability and quality and to find measures and strategies for conflict solution. Using the above explained 100 realisations of the developed future climate scenario (A1) as input all components of the water balance are simulated in a spatially distributed form over the whole investigation period of fifty years (2001-2055). The resulting stream flows are then compared at all relevant river cross-sections with given water demands and, as soon as water deficiencies occur, predefined operation rules for the existing reservoirs and priority rankings for water allocation are applied to avoid or reduce the deficiencies. Inavoidable deficiencies are registered and finally analysed in a summarizing form, in particular in form of probability distributions of water deficiencies, the exceedance of predefined threshold values of, for example, stream flow or related criteria (hydrological, ecological, economic or others). These results represent essential products since they can be directly used for decision support in solving practical problems by the responsible regional authorities, actors in communication with stakeholders in the widest sense.

6) Three special sub-regional studies are implemented in the Spree/Havel river basin with the ArcGRM-GLOWA model as an interlinking tool for the basin wide integration of water management. These studies concern:

a) the upper Spree river basin where special focus is on the problems and conflicts resulting from the effects of about 100 years extensive lignite open pit mining and the abrupt closure of most of the mines in course with the German reunification (SP 2.1)

b) the regulated wetland subbasin Spreewald in the middle part of the Spree river basin, with some parts classified as biosphere reserves, where the focus is on the role of this area as valuable ecosystem with multifunctional use for agriculture, forestry, fisheries, recreation and nature protection (SP 2.2)

c) the lower Spree and Havel river subbasins with the developing urbanized region of Berlin where the focus is on the principal problems of such regions concerning water supply, waste water treatment and associated ecological, especially water quality (SP 2.3).

Many of the problems in regions b) and c) are dependent on an appropriate water management in the upper Spree basin what makes the cross-regional basin wide integration so important and necessary.

7) Another case study region is the upper Unstrut river basin in the mountain forelands of Thuringia (SP 3), which include favourate agricultural areas in the Thuringian basin surrounded by the mountain ranges Thuringian Forest, Harz and Ohm mountains. Due to its character this region differs characteristically from the Spree/Havel river basin. Focus is here on the sustainable development of agriculture considering Global Change impacts, aspects of water quality, surface and groundwater interaction, especially in flood plains, and questions of flood plain design (e.g. renaturation) and management. The studies are coordinated with the studies in the whole Elbe basin as a “nested study” with strong involvement of regional stakeholders, in particular farmers.

In summary it can be concluded that some innovation has already been achieved in GLOWA-Elbe and that results can be used for the solution of practical problems and conflicts.

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GLOWA RELATED RESEARCH COVERING THE WHOLE ELBE BASIN

H. Behrendt[1], P. Döll[2], H. Gömann[3], C. Julius[3], V. Krysanova[4], M. Soukup[5], S. Vassolo[2] and F. Wechsung[4]

[1] Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin (behrendt@igb-berlin.de; http://www.igb-berlin.de)
[2] Center for Environmental Systems Research, University of Kassel, Kurt Wolters Str. 3, 34109 Kassel (doell@usf.uni-kassel.de; http://www.usf.uni-kassel.de/usf/)
[3] Research Association for Agricultural Policy and Rural Sociology (FAA), Ferdinand-Lassalle Str. 1, 53175 Bonn (faabonn@t-online.de; http://www.faa-bonn.de)
[4] Potsdam Institute for Climate Impact Research (PIK), Telegrafenberg A31, 14473 Potsdam (wechsung@pik-potsdam.de; http://www.pik-potsdam.de)
[5] Research Institute for Soil and Water Conservation Praha, Czech Republic

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Keywords: Nutrient inputs, nutrient balance in agriculture, plant growth, population development, water use

Abstract

First results regarding the establishment of an unified database for the modeling of the whole Elbe basin and a complex model system which spans the range from the human activities in agriculture, population development and water uses to the flow conditions and nutrient inputs in the basin are presented.

Establishment of harmonized databases and tools for analyses in the entire Elbe basin

Within the last years numerous data sets and models were prepared and applied for the German part of the Elbe basin, in particular in the frame of government (BMBF and BMU) funded German research programs (Behrendt et al., 2000; Wendland & Kunkel, 1999; Becker et al., 2001, Döll et al., 2001). For the application of these data and tools in GLOWA-Elbe the following tasks need to be solved:

- Establishment of a joint GIS-database for the entire Elbe river basin in cooperation with Czech partners
- Further development of available models to prepare them for simulations under changing climatic and other changing conditions, including socio-economic changes
- Implementation of improved or new moduls for simulating water and nutrients dynamics, including the flows of water and associated substances
- Adaptation of individual models, which were successfully applied in Germany, for regional analyses in the Czech and Austrian-part of the Elbe basins
- Preparation of methods and tools to integrate available sub-models in larger and generalized frameworks for application in different parts of the Elbe
- Definition or derivation of preliminary selected scenarios for the further development of conditions in the Elbe basin.

Based on the experiences in modeling nutrient inputs into the river system of the Elbe (Behrendt et al., 2000) and the cooperation with the Research Institute for Soil and Water Conservation (Praha, Czech Republic) a harmonized database is under construction. For the regional investigations in the Czech part of the Elbe basin this part was subdivided into 25 sub-catchments having a mean catchment area of 2000 km². GIS data for landuse, elevation, the river network, administrative boundaries, hydrogeology and soil were harmonized in both partner countries to establish a unified database for the whole Elbe basin. Moreover, statistical data on population, agriculture, waste water treatment were collected at the level of municipalties, districts and for the whole countries, and then overlaid with the administrative boundaries to establish thematic maps for the further analysis of nutrient inputs and socio-economic conditions. Most of these data are needed as input for modelling the nutrient inputs into the river system of the Elbe.

As an example Figure 1 shows the long-term changes of nitrogen surplus in the agricultural area of the Czech Republic and the German states Brandenburg and Saxonia-Anhalt. From this figure it might be concluded that a subdivision of the Elbe basin into sub-regions and sub-catchments would be necessary or useful to better assess the different natural and socio-economic conditions.

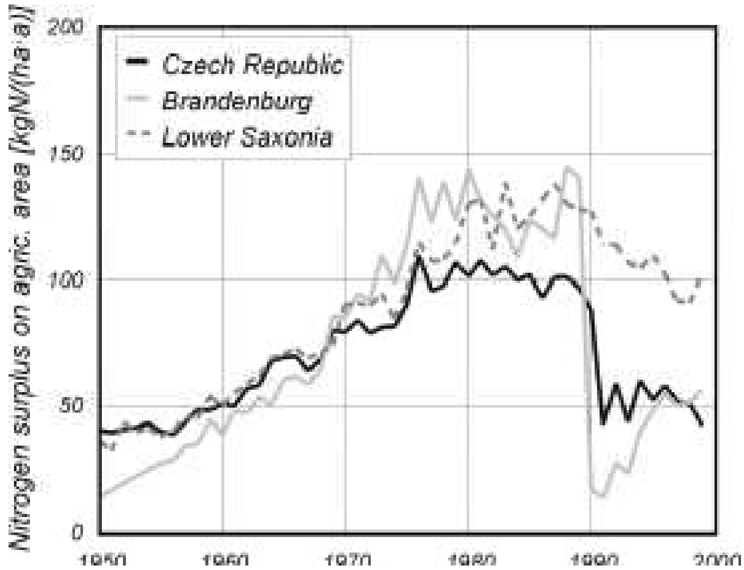

Fig. 1: Changes of the nitrogen surplus on agricultural areas in Czech Republic, Brandenburg and Saxonia-Anhalt from 1950 to 1999.

For the German part of the Elbe the data series of monitored water quality in rivers, in groundwater and tile drainage were completed until the year 2000. For the Czech part this data completion is under way.

A new result concerning the role of tile drainage for water and nutrient inputs into the rivers of the Elbe basin should be mentioned. From experimental studies in the Czech Republic it was concluded that water flow from tile drainage represents 60% of winter and 20% of summer precipitation (on average). This is in both seasons about 10% more than found for German conditions. Further investigations are required to clarify this and determine the possible dependency of drainage yield on the amount of precipitation. After finishing this data collection and analysis the available nutrient input model MONERIS (Behrendt et al. 2000) will be applied also for the Czech part of the Elbe basin.

Investigation of the impacts of the global food market and European policy on land use pattern and agricultural production in the Elbe basin

Special attention in GLOWA-Elbe is on agriculture viewing at its acreage-intensive production and its major role for the water balance and the pollution of water resources. Facing an increasing liberalisation of international trade (WTO, east-enlargement of the EU), extensive changes are expected in agricultural land-use and resulting consequences for water resources availability. There is a clear trend observed towards a dual development of, on the one hand, favoured regions with an intensive agricultural production and, on the other hand, less favoured regions with a decrease of farming. The EU policy is designed to counteract these trends of segregation.

To analyse and understand the impact of world-wide developments of the agricultural markets on land-use, environment and agricultural production in the Elbe river basin special studies supported by modelling are implemented which take into account agricultural as well as environmental policy measures. Here the following aspects are of particular interest and therefore included in the analyses:

- The liberalisation of agricultural markets and the coupling of subsidy payments for the fulfilling of environmental requirements
- The incorporation of climate and water resource interactions in the modelling of agricultural production and hydrological processes
- The impact of potential policy measures concerning agricultural production on the environment and socio-economy.

The related agricultural sector analyses are based on expected future developments of the global agricultural commodities market, which are calculated by means of the partial equilibrium model WATSIM (von Lampe, 1999). Based on that the resulting development of agricultural production on district scales is estimated by using the Regionalized Agricultural and Environmental Information System RAUMIS (Cypris & Kreins, 1998). The results of this top-down approach are then compared with those received from a detailed regional study in the Thuringian Unstrut river basin (subproject 3) and evaluated. Following the evaluation agricultural land use scenarios for the future will jointly be developed.
These scenarios are then applied in the following impact analyses, together with climate change scenarios developed in subproject 4, to estimate the resulting changes in the regional water and nutrient balances, in agricultural yield, and in the potential of water resources contamination. For this purpose the eco-hydrological model SWIM (Krysanova et al., 2000) and RAUMIS are applied in a coordinated way. In summary the following steps are undertaken in the applied integrative approach:

- validation of the applied models for the reference period (1979 - 2000) with current land use and climate conditions
- application of the models with scenarios of changing climate and land use, including land use patterns, to determine the resulting changes in the major water and matter flows and balances, especially nutrients, at river basin scales.

The eco-hydrological model SWIM is capable to simulate the spatial and temporal dynamics of physical, chemical and biological landscape processes at the scale of hydrotopes and river basins. It is also sensitive to changes in atmospheric CO_2. The simulation results include:

- water balance components (evapotranspiration, direct runoff, groundwater recharge)
- Crop and timber yields
- Leaching of nitrate into groundwater and surface water bodies
- Leaching of organic nitrogen and phosphorous compounds into surface water
- Soil erosion

Results received for the different scenarios will be intercompared and conclusions drawn on the “best” or most sustainable agricultural practice for the expected future conditions. These results will be compared with those received from the coordinated application of RAUMIS and MONERIS.

Finally, the costs of environmental policy measures to decrease agricultural nutrient input will be estimated and in conclusion recommendations will be given for appropriate strategies supporting sustainable development in the region considering also the effects of agricultural production on water quality.

Population scenarios for the Elbe region

Population development is one of the essential socio-economic characteristics for the future of a region. To derive a consistent population data for the Elbe region two population scenarios for the period 2000 to 2050 using a time step of 5 years were generated with a spatial resolution of 2.5 minutes. The generation was based on the two global IPCC SRES scenarios A1 and B2 (Nakicenovic and Swart, 2000), where only four world regions are distinguished. Thus the downscaled scenarios for the Elbe region fit either to the global A1 or B2 scenarios as reference. A1 describes a strongly globalized future world (rapid economic growth, fast introduction of more efficient technologies, convergence of countries with strong social, cultural and economic interaction), while B2 refers to a less globalized world (less rapid economic growth, reduced materials intensity, stronger environmental protection and emphasis on local solutions to achieve economic, social and environmental sustainability).

For both the German and the Czech part of the Elbe river basins, these global scenarios have been translated into a population development in which the general decrease in population due to the low birth rates is less strong in case of A1 than B2 (due to the higher immigration rate). In case of the Czech Republic, the "medium" prognosis of the UN (1998) for the related world region was applied, for Germany two different versions of the specific prognoses of the Federal Office for Statistics (2000).

Large scale generalization of results

It should be pointed out that large scale applications of the global integrated water quantity model WaterGAP 2 (Döll et al., 2001) in the five GLOWA river basins Elbe, Danube, Draa, Oueme and Volta form a part of the research activities of this group. They are conceived to allow and facilitate an intercomparison and generalization of the results received in the five different basins along a north-south gradient across Europe and Africa. Recent improvements in WaterGAP 2 concern the possibility to distinguish the following water use sectors: households, industry (water for cooling or manufacturing), irrigation and livestock.

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SUSTAINABLE WATER RESOURCES MANAGEMENT AND REGIONAL DEVELOPMENT IN THE UPPER SPREE RIVER BASIN HEAVILY INFLUENCED BY LIGNITE OPEN PIT MINING

U. Grünewald[1], D. Ipsen[3], M. Kaltofen[1], M. Karkuschke[2], H. Koch[1], F. Messner[2], M. Schramm[4], S. Schuster[3], K.-H. Simon[3], A. Wehrle[3] and O. Zwirner[2]

[1] Brandenburg Technical University of Cottbus, chair of hydrology and water resources management ; PF 101344; 03013 Cottbus
(Uwe.Gruenewald@tu-cottbus.de; http://www.tu-cottbus.de)
[2] Centre for Environmental Research (UFZ) Leipzig-Halle, Department of Economics, Sociology and Law, PF 500136; 04301 Leipzig
(messner@alok.ufz.de; http://www.ufz.de)
[3] University of Kassel, Department of Urban Planning and Landscape Planning, Institute for Empirical Research of Planning Issues, Moenchebergstrasse 17, 34119 Kassel
(aep.glowa@uni-kassel.de; http://www.uni-kassel.de/fb13/AEP/)
[4] WASY Ltd. Water resources planning and system research; Branch office Dresden; Goetheallee 21; 01309 Dresden
(m.schramm@WASY.de; http://www.wasy.de)

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Abstract

The project focuses on problems of water availability in the Spree river basin, which is heavily influenced by 100 years of excessive lignite open pit mining. The extreme dimension of these problems (concerning water quantity and quality) is a threat for the ecosystems of the whole river system and other areas located downstream. Scenarios of future development are derived and resulting impacts analysed, using the GLOWA-Elbe Integration Approach and well established modelling tools such as the further developed, spatially distributed long-term hydrological simulation and water management model ArcGRM-GLOWA. First results are already provided by use of this model.

Problem description

Major problems in the Spree river basin are the insufficient water availability and quality due in particular to the excessive open pit lignite mining over the last hundred years in its upper part. It resulted in a cone of groundwater depression in an area of about 2000 km^2 representing a groundwater deficit of about 10 billion m^3. In the past the missing runoff from this area and remarkable infiltration losses through the river beds were more than compensated by the amount of groundwater, pumped out of the mining araea into the river system. Today's problems of water availability are caused on the one hand by the rapid decrease of pumped and released groundwater in the mining area from 33 m³/s to 12 m³/s (due to the abrupt closure of most mines after the German reunification) in connection with the linked phenomena of missing natural runoff from the area of groundwater depression and the infiltration losses of river water through the river beds. The refilling of the cone of depression will need a time span of several decades during which the situation will slowly be improved, especially in the second phase.

On the other hand existing water users want to keep their water demand at the former level when the water yield was stable and sufficient. New is the strongly increasing additional demand for water to fill up the mining lakes in correspondence with the rising groundwater table. If this water cannot be supplied the mining lakes will be filled up only by acid groundwater, which has pH values down to 2.5. This would be a threat not only in the mining lakes itself but also for the connected river system and other areas located downstream. A fast filling process with surface water can prevent the exfiltration of the acid groundwater into the mining lakes and thus would ensure an appropriate water quality. Since the Spree river basin belongs to the driest regions in Germany it is particularly difficult to supply the required additional water.

Derivation of strategies for water resources management and future development

The investigations in the Spree river basin have been choosen as pilot case study for the application of the developed GLOWA-Elbe Integration Approach. Accordingly as the first step, a general analysis of the conflict situation has been executed and future scenarios were derived together with involved stakeholders. Using qualitative interviews, important information could be obtained concerning the decision making structure and the interest constellation in water use, including the conflict. Based upon this information, essential global and regional boundary conditions of future development in the Spree river region, affecting water yield and demand, were considered and possible effects discussed with the main water users and water authorities. As a result two most important boundary conditions of the water conflict could be identified:

- Climate change and climate protection policy: Because of the described high risk of water shortages any additional reduction of water yield due to global warming aggravates the water use conflict, may lead to damages of ecosystems by acid outflows from the mining lakes, and may induce economic losses of water intensive industries.
- Developments in the electricity market: The production of electricity based on lignite mining in the Spree river region induces an increase in the regional surface water yield through pumped and released groundwater, and thus reduces the present water use conflict. However, the liberalisation process in the electricity market, changing regulations of the market and of power production as well as strategic global management activities may lead to a decrease in electricity production and hence to a reduced water availability in the Spree region. Last but not least decreased electricity production also implies further reductions in the employment rate and in the income since the energy sector is the region's dominating economic factor.

The analysis of options for the regional decision makers to solve the water use conflict reveals that at present the key problem is the high demand for water to fill the mining lakes and ensure an acceptable water quality. Meeting this demand is very important for the surface water systems in the whole region. Therefore it will get a higher priority in the case of reduced water yields due to changing boundary conditions. This would cause costs in the form of profit losses of other water users (e.g. fishery). Alternatively, one could prefer the additional chemical treatment of mining lakes by an in-lake approach. This also offers possibilities to use the lakes economically, e.g. for tourism. As a consequence, two main fields of options were identified:

- river basin wide water management,
- additional chemical treatment of mining lakes.

Combining these two main options for action with the given scenarios of expected changes in the boundary conditions, in particular climate, results in a set of scenarios to be investigated. It is presented in a summarized form in Fig. 1.

	boundary conditions						options for action						
	climate protection policy advises ...			developments in the electricity – market lead to ...		...	changes in river basin wide water resource management ...			additional chemical treatment of mining lakes ...			...
focal point of Scenario	no climate change	moderate climate warming	...	moderate reduction of mining	...	...	are not planned	result in a high priority of filling up the residual lakes	...	is not done	is done in-lake	...	...
reference	x			x			x			x			
climate		X		x			x			x			
filling up		X		x				x		x			
treatment		X		x			x				x		
...													

Fig. 1: Selected scenarios for the Spree River Basin to be analysed

For the evaluation of the results of these scenario analysis, indicators and criteria have to be defined (Step 2 of the Integration Approach). Based on the conflict analysis and the interviews with local authorities and water users potential effects the following indicators have been identified as most important: amounts of water yield, available to meet the demands of the water users, in particular minimum streamflows required for ecological purposes, for cooling water in power plants and for fishery; for filling up the mining lakes to appropriately rise the pH value. Among the water-related economic indicators are: delayed economic use of the recultivated lake landscape, profit reductions of economic enterprises, and employment figures.

Step 3 concerns the analysis of the impacts occuring if the derived scenarios are applied. A reference scenario is required against which the results of the impact analysis can be compared. This reference scenario is defined by the assumption that no climate change will occur and that no additional measures will be planned in comparison with the present water resource management strategy. This strategy was chosen by the responsible water authorities in the Spree river basin (in the states of Saxony, Brandenburg and Berlin) as well as by the company LMBV, responsible for water budget and landscape rehabilitation of the former active mines. It defines in particular the priority list for the different water users and the detailed operational concept for filling the mining lakes, especially the time frames and the water quantities as well as the corresponding water releases from the existing reservoirs. A special data model according to the described strategy was made available to the project.

The enormous extent, detail and complexity of modelling the considered processes of water yield, supply, demand and water resource management can best be illustrated by the following characteristics:

- more than 170 sites river cross sections are considered,
- about 400 different water users with their seasonally ad interannually changing demand are included,
- water releases of 14 reservoirs are modelled,
- over 40 additional so called "dynamic elements" were introduced to describe processes, not reflected in the standard model elements,
- more than 200 indicators were defined and are continuously registered during computations.

Accordingly a comprehensive data base model had to be built for each scenario. The main tool for the scenario analysis, covering the continuous budgeting of water yield and demand at al reference sites mentioned before, including the continuous simulation of water resource management and reservoir operations, is the long term water management model ArcGRM. It is capable of implementing the following principal modelling steps:

- stochastic Monte-Carlo-simulation of system inputs, such as precipitation or discharges, distributed at all sites of interest and over the planning period,
- deterministic modelling of water demands and of their detailed budgeting with water yield as well as the interaction of demand and supply through water resource management (e. g. reservoir operation, different priorities of water users),
- registration of related to the matter of investigation system states (e.g. water reservoir levels, discharges at different sites, deficits of water supply),
- statistical analysis of these registered system states.

The model is also capable to take into account nonstationarity of water yield, demand and management processes.
These powerful capabilities of the model allow to link together different time frames of water management options, such of filling up the mining lakes, histories and scenarios of rules of reservoir operations, the development of industry and mining as well as changes in water yield caused by climate change in the investigate period (here until 2050). For the first application of the ArcGRM climate data set was prepared in the firm of hundred samples of synthetic climate data each of a length of 50 years. These synthetic climate data were used as stochastic input for the ArcGRM. By using them it became possible to link the stochastic approach of the longterm water management model to the output of a climate model.
The resulting model is called ArcGRM-GLOWA. It allows and is now prepared to carry out impact analysis for scenarios, which consider climate change, in this case moderate climate warming (see fig. 1). To illustrate the type of results provided by the analysis fig. 2 shows an example. Estimated reliabilities of minimum streamflow at the gauge Große Tränke/river Spree, required to fulfill municipal and industrial water demand as well as ecological purposes in Berlin, are represented in the figure for the year 2010 with four different management options (scenarios). "Große Tränke" is the main inflow gauge to the Berlin area. These results were achieved in an earlier study with the reference scenario.

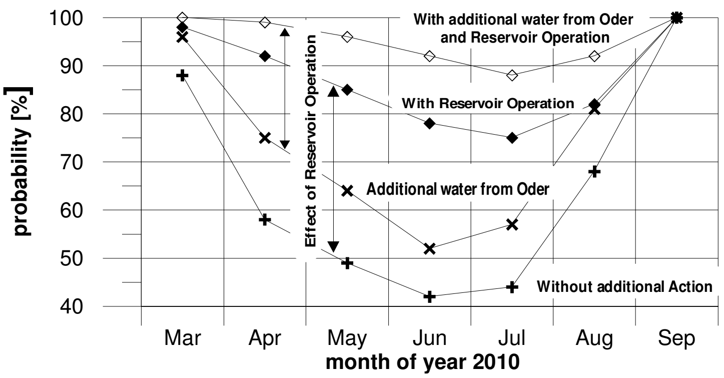

Fig. 2: reliabilities of minimum streamflow at the gauge Große Tränke/river Spree under various management options

The reliability of minimum streamflow is expressed by the probability, that the modelled streamflow reaches or exceeds the defined threshold value. For several months of the chosen year 2010 the corresponding probabilities are shown. Each curve represents a different management option: Water transfer from the Oder to the Spree by pumping water through the Oder-Spree-Channel and by water release from the reservoir Lohsa II in the Upper Spree river, supporting the streamflow in Große Tränke. For each month one can calculate the impact of the reservoir operations or of pumping water from the Oder river.
At that point a connection of the model with the economic evaluation activities (Step 4) will be achieved. Based on price, turnover, and cost data of water users that have been collected up to now, the effects on streamflow of water management options being modelled with ArcGRM-GLOWA will be linked to cost functions of important water users, with the costs

being dependent on water availability and time. In this way, the economic welfare effects can also be modelled by ArcGRM-GLOWA.
However, not all scenario effects can be evaluated in terms of monetary welfare (e.g. employment effects, various ecological effects etc.). Therefore, all effects that are essential but cannot be expressed in welfare terms will be included in the evaluation as well. The complete set of scenarios, improved and complemented in the participatory discussion process with the stakeholders, will be subject of a multicriteria analysis. The first discussion in a workshop with the decision makers is planned to take place in spring 2002. Regarding the comprehensive multi-criteria evaluation a design of the participatory evaluation process has been elaborated and the possibilities to integrate the existing software programmes into the process have been examined.

Landscape conference

In parallel to the above explained impact analysis, interviews, workshops and finally a landscape conference were implemented to find out the meaning and so-called "future scenarios" of of the citizens in the region Niederlausitz, which is most heavily effected by the mining activities. Key questions to them were: The Niederlausitz in fifty years? What is this region going to look like? What is it supposed to look like? The two workshops and the landscape conference were underlain with two rather unusual hypotheses:

First, the thinking in a time frame of fifty years. Usually, planning and development considerations for a region or landscape are done for much shorter periods, for good reasons: It is impossible to predict or prognose the developments for half a century. Yet if we started from the assumption that if there is a way to influence the future, then only by thinking about the developments and possible alternatives today. The results of these considerations are called 'scenarios'. Since we implemented this process in workshops and landscape conferences with the citizens of the Niederlausitz we call the results 'citizens scenarios'. These scenarios are based on the everyday experience of the people, which sociology defines as 'Lebenswelt'.

This leading to the second unusual hypothesis: the participation of citizens in the development of scenarios about the future of their landscape. The reasons for this method are twofold: on the one hand, our society is changing more and more from a state-regulated society to a society shaped by the engagement of its citizens (civil society). On the other hand, it is very reasonable not only experts merging their knowledge in order to point out feasible solutions but also involving citizens in this process. After all, they are the ones whose interests and actions shape the development of regions.

The scenarios developed by the citizens of the Niederlausitz have two striking things in common: first, they are neither homogeneous nor linear. Different future developments are thought at once. Wilderness stands beside a type of agriculture, which produces commodities for particular local industries. „Nature-tourism" in search for quietness stands beside „action-tourism"; traditional villages beside facilities for research on acidic lakes. The scenarios are multi-coded; contradictions are solved by spatial differentiation.

Second is the realism, with which the initial conditions are accepted in the development of the scenarios. The population decline is accepted, and the opening of the border to Poland is seen as a necessary and reasonable development within the framework of the EU-extension.

That way, the citizens scenarios present interesting possibilities, which may serve as corridors for possible action towards a complex structure of the region's future.

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MANAGEMENT STRATEGIES FOR REGULATED WETLAND ECOSYSTEMS IN THE CONTEXT OF GLOBAL CHANGE: CASE STUDY SPREEWALD

M. Grossmann[1], O. Dietrich[2], U. Bangert[3], K. Schwärzel[4], G. Vater[3], V. Hartje[1], I. Kowarik[3], J. Quast[2] and G. Wessolek[4]

[1] TU Berlin, Institute of Landscape and Environmental Planning - Landscape Economics, FR 2-7, Franklinstr. 28/29, 10587 Berlin
(grossmann@imup.tu-berlin.de; http://www.tu-berlin.de/fak7)
[2] ZALF Müncheberg, Institute of Hydrology, Eberswalderstr. 84, 15374 Müncheberg
(odietrich@zalf.de; http://www.zalf.de)
[3] TU Berlin, Institute of Ecology - Ecosystem Science & Vegetation Ecology, Rothenburgstr. 12, 12165 Berlin
(ulrich.bangert@tu-berlin.de; http://www.tu-berlin.de/fak7)
[4] TU Berlin, Institute of Ecology - Soil Science, Salzufer 11-12, 10587 Berlin
(kai.schwaerzel@tu-berlin.de; http://www.tu-berlin.de/fak7)

Keywords: wetland, Spreewald, water management, ecosystem, hydrology, land use, nature protection, recreation, economic valuation, water allocation, global change,

Abstract

The Spreewald is a floodplain wetland with a highly regulated system of distributaries and canals in the middle reaches of the Spree River Basin. An actor oriented, ecosystem approach to watershed modeling is adopted with which effects of management and policy options on the water balance, environmental and economic functions of floodplain wetlands can be assessed in the context of effects of global change on climate, agricultural development and water availability in the river basin. Key features of the approach are: (1) participation of stakeholders in identification of issues for modeling and scenario formulation (2) data transfer and scaling up of ecosystem process models to a watershed scale based on hydrological response units derived from GIS analysis of available data (3) direct implementation of a wetland water management and water balance model into a hydrologic river basin management simulation model (4) a spatially explicit economic optimization model to estimate effects of changes in water availability, water use rights and land use policy on land use and water management on a landscape scale

Introduction

The Spreewald is a wetland area within the middle reaches of the Spree River, which split up into several branches that meander through a wide floodplain. Major current land and water uses are for agriculture, especially fodder production, forestry, nature protection, fisheries and recreation. During the last century, large areas of the floodplain have been diked and drained in order to intensify agricultural production. The natural system of distributaries has at the same time been increasingly canalized and regulated through the construction of weirs and pumping stations, both for the purpose of flood control and stabilization of water levels. As a result of these physical changes and the related streamflow control and management practices, the natural dynamics of the floodplain are impeded.

Because of the negative climatic water balance during the summer months, current land use patterns are reliant on additional water from the Spree River. Ample supplies of surplus water were until recently provided from drainage of opencast coal mines in the headwaters. With the demise of coal mining, water has become an increasingly contested resource – both within the Spree River Basin as a whole and amongst the water users within the Spreewald. Compounded with climate change, the current summer water deficit is likely to become more aggravated. At the same time, changes in land use policy are driving changes in land use patterns and associated water management regimes. With the gazettement of the Spreewald as a UNESCO Biosphere Reserve, the restoration of natural floodplain dynamics has become a major development goal [cf. 4], while shifts in agricultural policy are reducing the incentives for intensive agriculture production on wetland sites.

The primary objective of the subproject is to assess scenarios of regional effects of global change on current and planed water resource management practices in the Spreewald sub basin. The aggravated summer water deficit with related water management conflicts and policy responses outlined for the Spreewald are typical for regulated fens and floodplains in many of the north eastern German lowlands [cf. 2]. The more general objective of the project is therefore, to develop methods and tools, with which effects of management and policy options on the environmental and economic functions of wetlands can be assessed at the sub-basin scale in the context of climate change, agricultural policy and water availability in the river basin.

Conceptual and methodological framework

The GLOWA-Elbe Integration Approach is the basis for the actor-oriented, ecosystem approach to watershed modeling adopted in the Spreewald subproject. Key features are: (1) participation of stakeholders in identification of core issues for modeling and scenario formulation (2) data transfer and scaling up of ecosystem process models (evapotranspiration and soil moisture dynamics, vegetation development, crop production and forest growth) to a watershed scale using hydrological response units derived by a GIS analysis of available data (3) aggregation of hydrologic response units to larger water regulation entities for the implementation of a wetland water management and water balance model in direct coupling with a river basin model (4) a spatially explicit economic optimization model to estimate effects of changes in water availability, water use rights and land use policy on land use and water management on a landscape scale.

Hydrological response units are distributed landscape entities (not necessarily contiguous) having a common climate, land-use and underlying pedo-topo-geological association controlling their hydrological dynamics [cf. 6]. With this concept the heterogeneity of the three dimensional properties of the drainage basin can be preserved and is therefore suited for spatial scale transfer of processes coupled to ecosystem structures. GIS analysis of available data on topography, pedo-geological association and land cover was used to generate hydrological response units on a 25*25 m grid. In a second step, these were combined to water regulation entities (Figure 1), which serve as basic units for modeling water management. These are defined as units of land whose water level can be regulated separately. Subsequently soil hydrological parameters were defined for each pedo-topo-geological association. These were aggregated to characterize total soil water storage capacities for each water regulation entity. Real evapotranspiration and biomass production is currently being calculated for combinations of classes of water level, pedo-geological association and land cover using the soil water and evapotranspiration model BOWAS for different series of climatic conditions [cf. 9]. A rule based vegetation development model for the conditions of the Spreewald, VEGMOS, was developed and validated on long-term vegetation monitoring data. The model predicts potential vegetation for hydrological response units on the basis of combinations of pedo-geological association, water level, land use and initial land cover [cf. 8].

Two basic types of models of water resource systems are employed for subbasin scale analyses: the water management model, ArcGRM Spreewald [cf. 2 & 3] which simulatesstochastic water resource behavior in accordance with a predefined set of rules governing water allocations and infrastructure operations, and an economic model, MODAM [cf. 5], that optimizes and selects allocations based on an objective function and accompanying constraints.

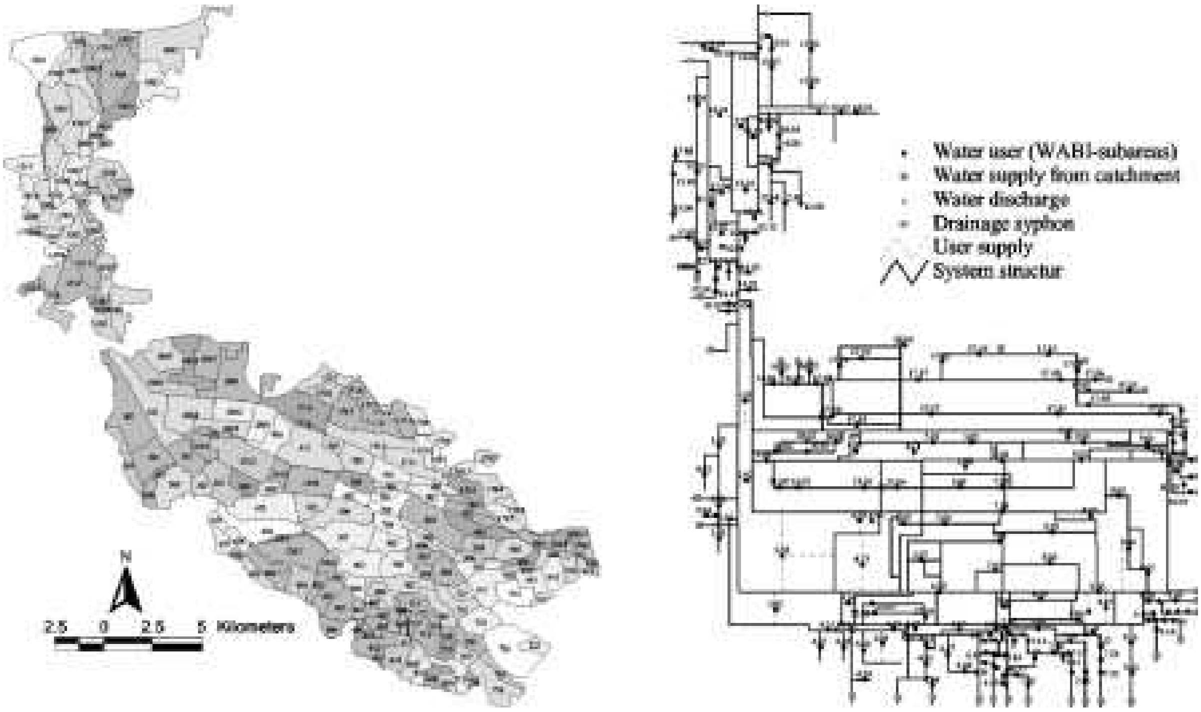

Fig. 1: Spatial distribution of water regulation entities used to model water management and their implementation as nodes in the Arc GRM Spree node-link network.

The ArcGRM Spreewald model is implemented as a sub-module of the larger scale basin wide ArcGRM Spree model. It is developed in a node-link network, which is an abstracted representation of the spatial relationship between the physical entities in the river basin. Nodes represent river reaches and demand sites and links represent the linkage between these entities (Figure 1). Inflows to these nodes include water flows from the headwaters as well as local rainfall drainage. Flows are balanced for each node in each time step and flow transport in the basin is calculated based on the spatial linkages. Each water regulation entity is implemented as a node. For these nodes the water balance and corresponding water level is calculated by the sub-model WABI [cf. 2] on the basis of the weighted sum of the evapotranspiration of the hydrological response units contained in the water regulation entities and externally defined water management regimes.

Basis for the economic model of water allocation are production functions for agriculture and forestry that include water as an input, and estimates of the value of environmental and recreational demands, to estimate the use and value of water by sector. Currently, a pasture fodder crop biomass and quality model is being developed on the basis of standardized data and a relative biomass production function from BOWAS for different combinations of water management regimes, soil types, potential vegetation and cropping practices [cf. 5, 8 &9]. Forest growth is to be modeled using the simulation model SILVA [cf. 7]. It is further intended to estimate value of recreational water use by travel cost method [cf. 10], and monetary value of environmental wetland functions using benefit-transfer methodology [cf. 1]. MODAM is a static linear optimization model for farms, which is currently being extended to include a spatial representation of all land and water users on the basis of representative enterprises and the water regulation entities of the ArcGRM Spree model. Water use costs for different scenarios are calculated by maximizing net benefit from different water management regimes and associated water demands subject to various restraints in the form of water and land use rights, environmental standards, water availability and agricultural prices and subsidies.

Stakeholder participation in formulation of wetland management scenarios

Stakeholders from the Spreewald are motivated to participate in watershed modeling on two accounts: (1) quantification of water demand and associated benefit of the Spreewald sub-basin for consideration in basin level water management (2) assessment of impacts of likely changes in water availability on current and intended land uses in the Spreewald.

Water management at a basin scale is regulated by state water authorities, who utilize the ArcGRM Spree model as a decision tool for allocations based on a ranking of water use priorities. Within the Spreewald sub-basin, short term decisions on water levels and water distribution are made in watershed advisory committees on the basis of existing formal and informal water use rights. Plans for major changes in land use and water management aiming to partially restore floodplain dynamics, retain water at the landscape level and increase the area dedicated to nature protection [cf. 4] are highly contested at the local level, as changes in land and water use rights will become necessary. Together with key stakeholders, existing use rights pertaining to land use, water level regulation and water allocation and their possible future changes are being identified and mapped.

The results are summarized as two scenarios of water management options for the Spreewald ("no substantial changes" and "restoration of floodplain dynamics & water retention") which will be assessed in the context of relevant regional effects of global change quantified in other GLOWA- Elbe subprojects (changes in rainfall and temperature [SP 4], in agricultural prices and subsidies [SP 1] and in-stream flow [SP 2.1]). Effects are to be assessed in terms of ecosystem integrity, economic and financial benefit, basin water use efficiency and feasibility of water management strategies.

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STAKEHOLDER DRIVEN INTEGRATIVE STUDIES OF WATER AVAILABILITY AND QUALITY IN THE URBANIZED REGION OF BERLIN CONSIDERING GLOBAL CHANGE IMPACTS

R. Oppermann[1], V. Wenzel[2], R. Eidner[1], W. Finke[1], B. Pfützner[3] and C. Rachimow[1]

[1] Bundesanstalt für Gewässerkunde, Außenstelle Berlin, Schnellerstraße 140, 12439 Berlin
(oppermann@bafg.de; http://www.bafg.de)
[2] Potsdam Institute for Climate Impact Research (PIK), Telegrafenberg C4, 14473 Potsdam
(wenzel@pik-potsdam.de; http://www.pik-potsdam.de)
[3] Büro für Angewandte Hydrologie, Wollankstraße 117, 13187 Berlin
(bah@bah-berlin.de; http://www.bah-berlin.de)

Keywords: impact assessment, alternative actions, indicators, management strategies, water management, river basin model, stakeholder, scenarios, water quality, water uses

Abstract

Conflicts in availability and uses of water caused by Global change and resulting environmental and socio-economic problems are examined in the urbanized region of Berlin (Fig. 1). Special focus is on population dynamics and the developments of settlements, power plants, and water utilities. Problems of water-resources management in the Berlin region result from the diversity of water uses in a very limited area characterized by scarce resources and inter-regional interactions in the Spree/Havel river basins. The socio-economic requirements on drinking water production, wastewater purification, power generation, and securing the navigability of waterways are closely connected with issues of water quality, the ecological conservation of waters, and quantitative water management. First scenario computations were made for various options following consultations with the stakeholders. The impact analyses use coupled models (Fig. 2). The studies on runoff generation, water management, and water quality are described in more detail.

Fig. 1: The area Berlin/Lower Havel

1. Integration Approach

The study represents an application of the GLOWA-Elbe Integration Approach in the Lower Spree and Havel river basins with urbanized region of Berlin. Developed aim of satisfying the various water demands and the given water-quality targets. Ecological, economic, and social aspects receive equal consideration in the Integration Approach. The main steps of this approach are applied according to the specified scheme in Fig. 2.

1.1 Definition of scenarios

For identification of possible solutions and potential conflicts, alternative management strategies (scenarios) are defined, which are superimposed by several variants of exogenous boundary conditions of Global Change (climate change, market liberalization, new technologies, etc.). To this end, potential activity fields were identified (regulation of streamflow and impoundments, waterworks, wastewater treatment plants, rainwater management, power plants, environmental protection). For each activity field several options for action were proposed (variations of investments and of capacity, structure, and performance parameters) from which the management strategies are compiled for comparison.

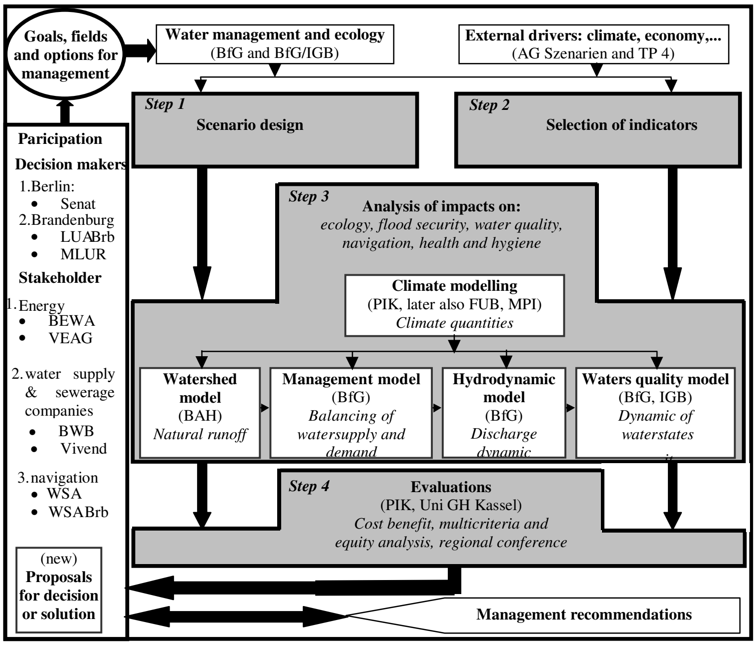

Fig. 2: Integration scheme

1.2 Selection of indicators

The impact analyses necessary for the comparative assessment of the given options for action (see below) require the selection of indicators, that allow the evaluation of the alternative management strategies. The criteria and assessments should reflect a catalogue of values that best fit to guiding principles and criteria for a sustainable development of the region and to the objective pursued by experts and stakeholders. Accordingly, the affected persons and institutions have to be consulted in this selection process. Conversely, this selection is subject to restrictions due to the tools available for the impact analyses in form of expertise, observed data, models and literature searches.

2. Impact analyses and results

Using the developed scenarios as input, impact analyses are performed that constitute were demanding step of work. It includes scenario computations with very complex models, e.g. the determination of the natural water resources from given climate data series, and on this basis, the long-term management of water resources considering all relevant uses, runoff dynamics, and water quality. First results of such analyses are available and briefly presented below.

2.1 Determination of water resources availability

Water resources in the tributaries of the rivers Spree and Havel in the Berlin region are computed by means of the rainfall-runoff model ARC/EGMO [1]. For model validation, the conditions were simulated and the elements of the water budget computed like real evapotranspiration, groundwater recharge, overland flow, and streamflow. These values are computed for given climatic scenario (SP 4) with the calibrated model. Altogether 100 realizations of the climate scenario are used in this computation analysis.

2.2 Water management

The balancing of available water and water uses in the catchment of the Berlin system of rivers and lakes was established by means of the long-term management model ArcGRM-GLOWA (SP 2.1), that is based on the model ArcGRM Spree/Schwarze Elster which had been used in the Berlin area previously [3]. The model takes account of the system character of the river basin and the stochastic character of the natural hydrological and meteorological processes. It allows to assess diverse and varying system conditions and to study the behaviour of the system under varying boundary conditions. Simulation of the natural process under consideration of the available water resources is based on balances made at 42 balancing profiles. The data on water users (power plants, water utilities, etc.) the operation regulations (weir controls, impoundments, water transfers), and the system discretization were updated for this study and reviewed in cooperation with the stakeholders Berlin Senate Administration for Urban Development (*SenStadt*), the Waterways and Shipping Office Berlin (*WSA Berlin*), the State Environment Agency Brandenburg (*LUA Brb*), the Berlin Water Enterprises and the power utility *BEWAG*.

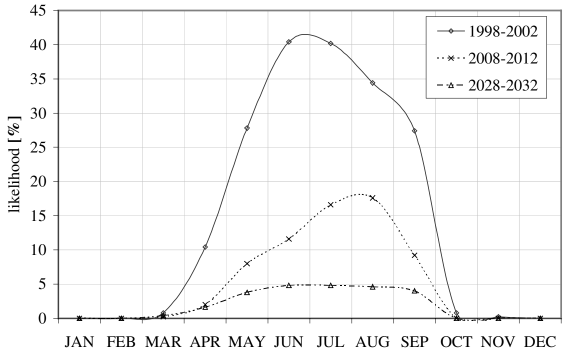

Fig. 3: Non-exceedance of the minimal streamflow of 8 m^3/s at the gauge Große Tränke

Viewing at required minimum streamflows in predefined balance points whitch are essential target criteria for water management and serve as control instrument, required and calculated flows are compared (balanced) and deficiencies in fulfilling the demand registered. These criteria have been recently redefined by *SenStadt*. On this basis, in a cooperative effort with *SenStadt* and *WSA Berlin* the algorithm for a new "Berlin-control strategy" to regulate water levels by weir regulation was formulated. It is better adapted to the requirements of the system of water bodies in and around Berlin. Together with *SenStadt* and *LUA Brb*, two water-use scenarios were developed, with targets for the years 2010 and 2025. First results are available. Very essential for the situation in Berlin is the upstream inflow into the system at gauge Große Tränke. Fig. 3 shows over three 5-year periods the development of water availability at Große Tränke ("1" in Fig. 1). Obviously the likelihood of flow remains below the required minimum threshold is the highest in summer. It rises to 40 % in the months of June/July during the period 1998-2002. The positive trend in later periods results from the progressing rehabilitation of the mining areas upstream that is associated with increasing inflow to Berlin. However, if climatic trend is taken into account, a deterioration may be possible in future periods.

2.3 Water quality modeling

Another important issue is the quality of waters. Two water quality models were used, which were coupled off-line with each other: (a) The watercourse quality model QSIM of the Federal Institute of Hydrology (*BfG*) and (b) an extended version of the model HavelMod of the Brandenburg Technical University Cottbus (*BTU*) for widened, lake-like reaches of the Havel in the centre of the study area. After validation, the seasonal variation of the year 1997 was simulated on the basis of daily values, which comprise besides measurements also generated results of a model-based system analysis. This made it possible to describe adequately the causal dynamics of the bio-chemical transformation processes in relation to changing boundary conditions (weather data etc.). The following aggregation of the simulation results in high temporal and spatial resolution is an essential component of variance analyses, including their assessment. In contrast to other statistical evaluation methods, the substance-related classification in classes of water quality (Fig. 4) is particularly noteworthy. It is based - unlike conventional methods (few random samples) - on much more detailed data sets. To make the connections between the individual water-quality features better visible, it is better to use less aggregated results. With the example of the first planning scenario, Figure 5 shows the concentration curves for the model boundaries and the interface profiles between the models. The filled areas (all grey) refer to the upper model boundary- the location of *BfG* at river Spree ("2" in Figure 1) and the hatched ones to the lower model boundary near Ketzin ("6" in Figure 1). The interface profiles between the models lie in between. The coupling point between QSIM and HavelMod

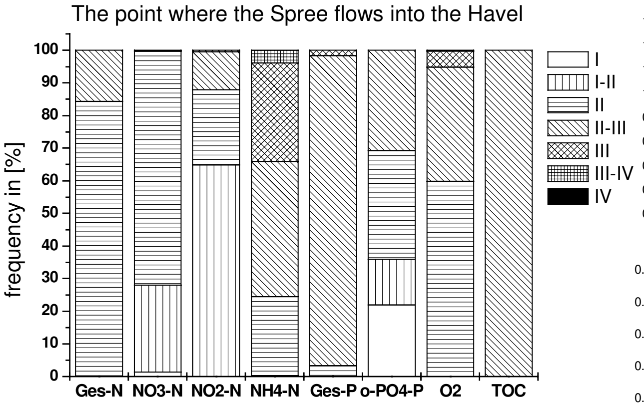

Fig. 4: Evaluation of simulated water-quality data at the mouth of the River Spree for substance-related quality classes

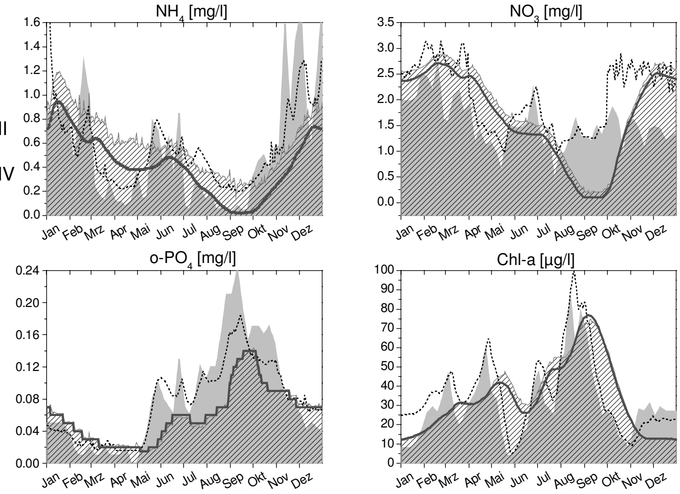

Fig. 5: Temporal variation of eutrophication parameters at prominent water sites

near the point where the River Spree flows into the River Havel ("3" in Figure 1) is shown as broken line, while the full line marks the transition from HavelMod to QSIM at the end of the series of lakes ("5" in Figure 1). With view to eutrophication, the following can be said: ammonium-N is nearly totally nitrified in summer or is incorporated in algal biomass. Also nitrate, that is readily available at the upper model boundary, is consumed nearly completely in September for algal growth in the lakes. The minimum of nitrate coincides with the algal maximum in the lakes and downstream thereof. The absence of nitrate favours the remobilization of phosphorus from the sediment, so that here no decrease of orthophosphate occurs during the summer algal peak, and algal growth is never limited by nutrient shortage. A pronounced clear-water stage, as it occurs in the River Spree at the end of May/ early June, was not observed in the lakes downstream. The high nitrate values at the point after the River Spree flows into the River Havel ("4" in Figure 1) between October and March are consequenc of the effluents from the sewage treatment plant Ruhleben, that discharges in summer into the Teltow Canal outside the simulation area considered in this study.

This results are essential for water quality management in the system.

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IMPACT OF GLOBAL CHANGE ON AN AGRICULTURAL REGION IN THE MOUNTAIN FORELANDS OF THURINGIA

B. Klöcking[1], H. Feige[2], S. Knoblauch[2], T. Sommer[3], B. Pfützner[4] and S. Leinhos[5]

[1] Potsdam Institute for Climate Impact Research (PIK), Telegrafenberg C4, 14473 Potsdam (kloecking@pik-potsdam.de; http://www.pik-potsdam.de)
[2] Thüringer Landesanstalt für Landwirtschaft (TLL), P.O.Box 100226, 07702 Jena (h.feige@jena.tll.de; http://www.tll.de)
[3] Dresden Groundwater Research Center (DGFZ e.V.), Meeraner Str. 10, 01217 Dresden (tsommer@dgfz.de; http://www.dgfz.de)
[4] Bureau for Applied Hydrology (BAH), Wollankstr. 117, 13187 Berlin (bah@bah-berlin.de; www.bah-berlin.de)
[5] Friedrich Schiller Universität Jena, Institut für Volkswirtschaft (S.Leinhos@wiwi.uni-jena.de; http://www.wiwi.uni-jena.de/Wirtschaftspolitik2)

Keywords: water availability and quality, land use change, climate change, intensive agriculture, Thuringia, Unstrut river basin, ecohydrological model, coupled river basin model, groundwater model

Abstract

The Thuringian Basin in the forelands of the mountains Harz, Thuringia Forest and Ohm mountains is a favourite agricultural region in Germany. The subproject aims at analysing the impact of Global Change (socio -economy, climate and other changes) on land use, water resources availability and quality, and on the overall economic and social situation in the region. The GLOWA–Elbe Integration Approach is applied focussing on (a) the actor based development of land use scenarios in the agricultural sector, (b) the analysis of the impacts of changes in land use and climate, (c) the evaluation of the results of these analyses and (d) the drawing of conclusions how a sustainable development of the region can be achieved or supported, viewing especially on agriculture.

Introduction

The Unstrut river basin covering an area of 6.300 km² of Thuringia is topographically and climatically highly heterogeneous. Annual precipitation ranges from more than 1000 mm/a in the headwaters of the Unstrut to less than 500 mm/a in the lower flat parts of the Thuringian basin. Because of its fertile soils (chernosems, vertisols) and the mild climate, this basin is a favourite agricultural region. Often during heavy rainfall events floods are generated in the mountainous headwaters of the Unstrut, which pass down the valleys more or less simultaneously and then may cause serious flooding in the inundation plains and other low lying parts of the basin. One of the major problems and conflicts is here, that agricultural use has been intensified in the flood plains during the last century. In that context rivers were regulated (shortened and diked) and the remaining flood plains drained so that flood retention capacities were drastically reduced. This creates major problems and conflicts in the area between agriculture on the one hand and communities and environmentalists on the other hand who increasingly ask for a renaturation of the rivers, riparian zones and flood plains to re-establish their flood retention capacities, ecological quality and functioning as well as their beauty for recreational purposes.

Therefore a basic aim of the subproject is to investigate the given possibilities for the solution of this conflict taking into account the impacts of the expected Global Change, and provide decision support for the responsible decision makers. Another general objective is to investigate the impact of Global Change on Thuringia in general, focussing on agriculture in the western, upper part of the Unstrut river basin (7.500 km²).

Conceptual and methodological framework

As in all GLOWA-Elbe subprojects the investigations in the Unstrut basin are based on the GLOWA-Elbe Integration Approach, which is specified for SP 3 in Fig. 1.

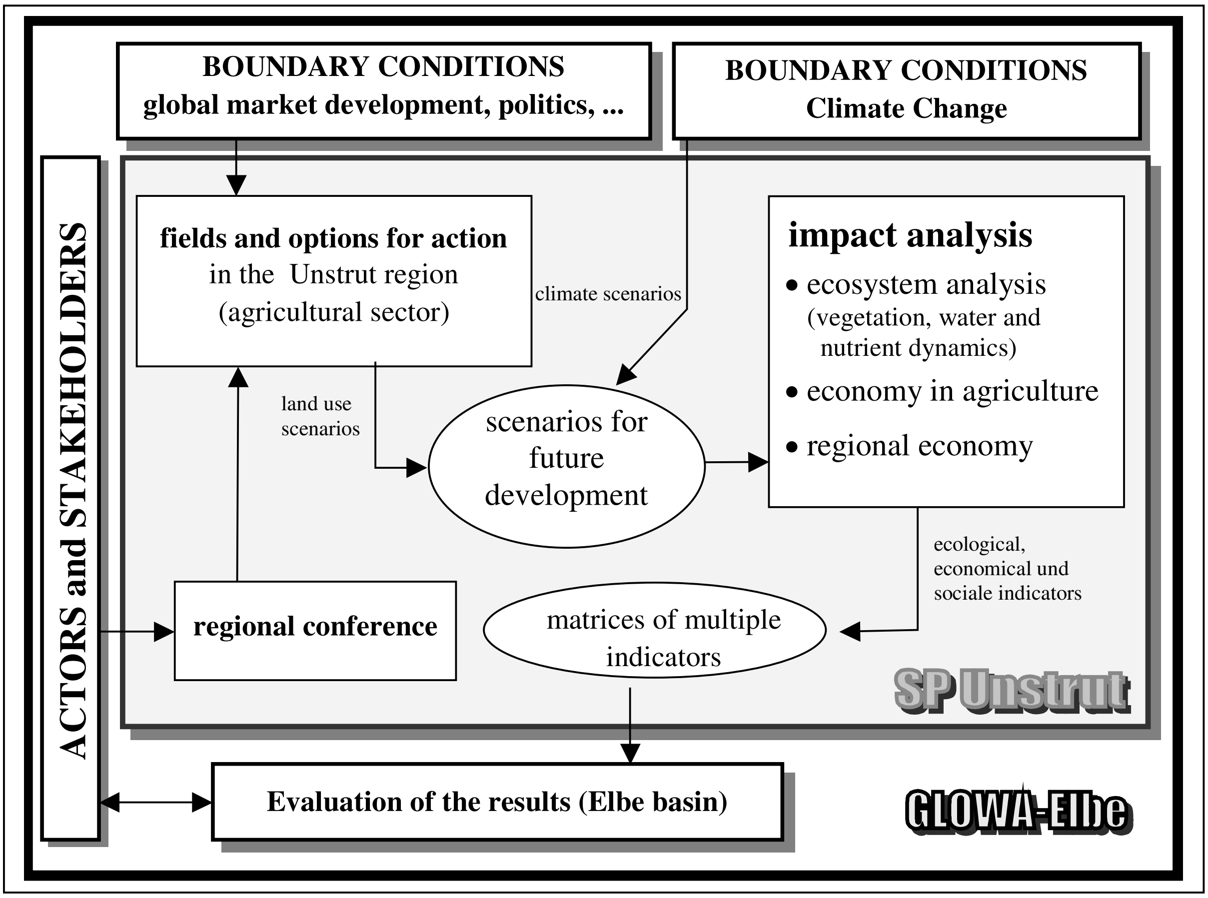

Fig. 1: Integrating concept of the SP Unstrut

Major emphasis is on the actor orientation of the approach. It has already been practicized in the development of land use scenarios briefly described below and in the identification of indicators of sustainability. It will be continued and intensified in a) the evaluation of the results of the impact analyses received with different development scenarios b) the subsequent drawing of conclusions concerning new strategies for regional development of the Unstrut region, required action programmes and so on.

The impact analyses include ecohydrological analyses and based on their results socio-economic analyses at farm and regional scales. Whereas the ecohydrological analyses are related to the river catchment the socio-economic analyses must be done for administrative units, preferably districts, or communities, or states. Therefore the latter ones will be done for the larger area about 7.500 km^2 covering nine Thuringian districts covering an area of. Some adjustment is required to integrate the two types of analysis.

Scenario development

A bottom-up approach is applied in the scenario development. It is based on the analysis of adaptation reactions of farmers considering the boundary conditions derived in SP 1 for Thuringia for the coming period. For this purpose farms in the region have been classified and five "typically farms" considered as representative for main and similar farm types were choosen for the detailed analyses. This classification was accompanied by a socio-economic survey at 30 farm leaders (in cooperation with the AEP GLOWA-Elbe partners at the GhK Kassel). Later the results will be extrapolated to the whole study area.
In the derivation of a referential scenario, representing the present conditions in Thuringia, a farm developing plan was used which assumes a strict realisation of the AGENDA 2000 resolutions. It is based on the farming management practices as applied in reality in the selected farms. The methodology was calibrated against the agrarian statistics of 1999.

Impact analysis

The ecohydrological impact analyses are done by means of the spatially distributed river basin model ARC/EGMO (Becker et al., 2002), which was successfully applied in a recent BMBF-project (Becker and Behrendt 2001). The impacts of changes in land use and climate and of different agricultural management practices on the water balance, water resources and agricultural plant production are studied in the entire study area. A GIS-based approach was developed and is applied, which allows to locate the land use scenarios, to reproduce the agricultural fruit patterns and rotation cycles in modelling.
Nested into these whole basin studies are studies in the subbasin above gauge Nägelstedt (760 km²). Focus in this nested study is on the above mentioned possibilities to improve the retention capacity of the riparian zone for water and nutrients by applying different management practices. A detailed monitoring program is running to support the modelling especially of the surface and grounswater interaction.
The coupled model consists at present of the river basin model ARC/EGMO, as used for the impact studies in the entire investigation area, and the groundwater flow model MODFLOW (Harbaugh and McDonald, 1996). It is suited for wider application in other river basins. It should emphasised, that results of the BMBF project "Revitalisierung der Unstrutaue" (TLU, 2000) are used in nested study, as well as the measuring program of water and nutrient dynamics in the riparian zone (groundwater and meadows). This program will be continued in the running subproject. Moreover lysimeter results of several years about nutrient leaching in dependence on agricultural use and soil conditions are available for model validation.

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DEVELOPMENT OF SZENARIOS FOR CLIMATE CHANGE IN THE ELBE REGION

E. Reimer[1], D. Jacob[2], F.-W. Gerstengarbe[3], W. Enke[1], D. Koslowsky[1], K. Bülow[2], P.C. Werner[3] and M. Wodinski[3]

[1] FU Berlin, Institute for Meteorology, Carl-Heinrich-Becker-Weg 6-10, 12165 Berlin (reimer@zedat.fu-berlin.de; http://www.trumf.fu-berlin.de)
[2] Max-Planck-Institute for Meteorology (MPI), Bundesstrasse 55, 20146 Hamburg (jacob@dkrz.de; http://www.dkrz.de)
[3] Potsdam-Institute for Climate Impact Research (PIK), Telegrafenberg A51, 14473 Potsdam (friwi@pik-potsdam.de; http://www.pik-potsdam.de)

Keywords: climate change, climate scenarios, climate model, climate model validation,precipitation, hydrological cycle, multivariate statistical methods

Abstract

Future climate scenarios 2001 - 2055 are calculated using different approaches: dynamica lclimate models ECHAM/REMO combined with statistical validation and interpretation, and a statistical model based on a new developed cluster analysis algorithm.

Introduction

For the analysis of Global Change impacts in the Elbe region future climate scenarios for the period 2001 – 2055 need to be prepared. Different approaches are used for this purpose, which also provide information about the uncertainties caused by model approximations and uncertain boundary conditions. The following models and analysis thechniques have been developed and are or will be applied:

- the dynamical climate models ECHAM (global) and REMO (regional), (MPI),
- statistical models based on REMO calculations and intense statistical validation, (FUB),
- statistical model based on a new developed cluster analysis algorithm (PIK).

Climate observation series were prepared at PIK and FUB for the relevant meteorological and hydrological parameters by utilizing of data from the German Weather Service, NOAA and Meteosat satellites and numerical analyses. These time series are used by MPI and FUB to intensively validate the regional model REMO (verification and control run). Forced by the atmosphere-ocean general circulation´model ECHAM4/OPYC3 szenario runs are underway with concentrations of greenhouse gases and sulfate aerosol according to IPCC (International Panel on Climate Change) scenario B2.

In parallel and for comparison climate scenarios for IPCC scenario A1 were calculated of PIK using a statistical model based on a new developed cluster analysis algorithm. It is capable also to provide information on the probability of occurence of simulated events.

Regional Climate Model REMO

The regional climate model REMO was used to study the hydrological cycle within the river ELBE drainage basin. The following validation-simulations have been performed:
(1979-98) 20 years 0.5 °, 10 years 0.16° horizontal resolution.

Encouraging results could be achieved in terms of the comparison of the model results with daily precipitation measurements. The simulated annual cycle of the precipitation is in good agreement with observations: the modeled monthly mean over 20 years fits well to the measurements, especially for September to June. In the late Summer, REMO underestimates the precipitation, but the calculated variability of the monthly sums is close to observations. The mean monthly sum of precipitation for the Elbe river basin over 20 years as calculated by REMO is 59.9 compared to the observations of 53.3 [mm/month].

Satisfactory in comparison with observations are also the simulated precipitation intensities for different horizontal resolutions. Only the precipitation intensity category 10-20 [mm/day] is underestimated by the model. This might be caused by the fact, that high rainfalls, observed at meteorological stations, are sometimes locally extreme, while in the model the precipitation is averaged over a whole model box.

Nevertheless, extreme events are simulated very well by the model, for example the high rainfalls in June 1990 in the area of Berlin. The model was also successful in other regions and for other extreme events, e.g. the Odra flood (Lorenz, 1999) and in the Baltic Sea area (Jacob, 2001).

To investigate the influence of climate change on the hydrological cycle REMO will be applied over a time period 2020-30. The coupled atmosphere-ocean general circulation model ECHAM4/OPYC3 is used as forcing for the control- and the scenario-runs. The changing concentrations of greenhouse gases and sulfate aerosol are chosen according to IPCC (International Panel on Climate Change) scenario B2. Preliminary results show a realistic behaviour.

REMO model validation and szenario modelling

In addition to time series of precipitation and other meteorological data for the Elbe area prepared for model comparison, satellite data can be used for the areal validation of REMO. By use of the cloud classification algorithm of Berger (1991) NOAA and Meteosat satellite data from 1990 up to 2001 were analysed for cloud coverage and cloud type. Special corrections were developed to discriminate low clouds, snow and sun-glint, in particular ver mountainous areas. The derived cloud coverages and types were compared to observations of the German Weather Service to determine the grade of discrimination of cumuliform and stratiform and other cloud types.

The comparison of all data with the REMO validation and control run is underway. The cloud analyses are used in combination with precipitation and weather observations to control the statistics of the local precipitation events in REMO.

The REMO validation was not only done at local, but also at larger scales, because the broad scale of the global model ECHAM, which forces the regional REMO model, can bring about problems in the simulation of the Middle European weather variations. Therefore special parameters were derived:

- a dynamical circulation index DSI (Nevir, 2001), comparable to the NAO index, which describes the overall circulation activity over the European and East Atlantic region,
- a group of objectively determined „Großwetterlagen“ for the Elbe region.

The REMO Model calculations are compared to the circulation pattern over the Elbe area and model statistics are ongoing to get corrections for the time distributions of Großwetterlagen and DSI for the climate model runs.

By statistical and neurofuzzy methods multivariate relations are determined to combine dynamic model features and local observations with the aim to produce model output statistics, which are useful to correct the ECHAM/REMO climate szenarios.

By using these statistics, including Großwetterlagen and the associated local precipitation, temperature and other relevant parameters, long time series are constructed for the years 2000 – 2055 for model grids or special hydrological reference areas. A first set of szenarios was calculated by an advanced statistical scheme (Enke and Spekat, 1997) for todays climate. 100 realisations of local climate wil be calculated by a stochastic mixing of discrete successions of Großwetterlagen with conservation of their time distribution, so that information about uncertainties can also be provided. The inclusion of REMO statistics into this procedure will quarante a more consequent consideration of dynamic model climate simulation.
For future application on very local scales (Berlin/Brandenburg) the Local Model (LM) of the German Weather Service has been installed. It will be used to investigate the recoupling feed backs of different landuse patterns and their changes on local climate in selected typical episodes.

Statistical Climate Scenarios

This model development was completed in three steps:

<u>1. Data handling</u>
369 stations (84 meteorological main stations, 285 precipitation stations) were thoroughly tested, corrected for errors and provided in a completed homogenized form for the period 1951 - 2000 (basic scenario) for the Elbe river basin. The following work was carried out:

- Testing of the data as to their completeness and homogeneity
- Determination and cataloguing of inhomogeneities with statistical tests
- Homogenisation of the data series
- Interpolation of all meteorological parameters (except precipitation) to the
- precipitation stations
- Quality test
- Incorporation of the homogeneous data sets in a generalized data base

<u>2. Model development</u>
The already existing basic scenario model (Werner, Gerstengarbe, 1997) was further developed in such a way that Monte Carlo simulations can be realised (scheme see Fig. 1). It now allowes for the first time to make statements about the probability of occurrence of single realisations. The following partial tasks were completed:

- Implementation of the Monte Carlo methodology in the model structure
- Implementation of an algorithm to adjust the starting state of the scenarios to previous
- observation periods by using different adjustment options
- Parallelisation of the program structure of the scenario model

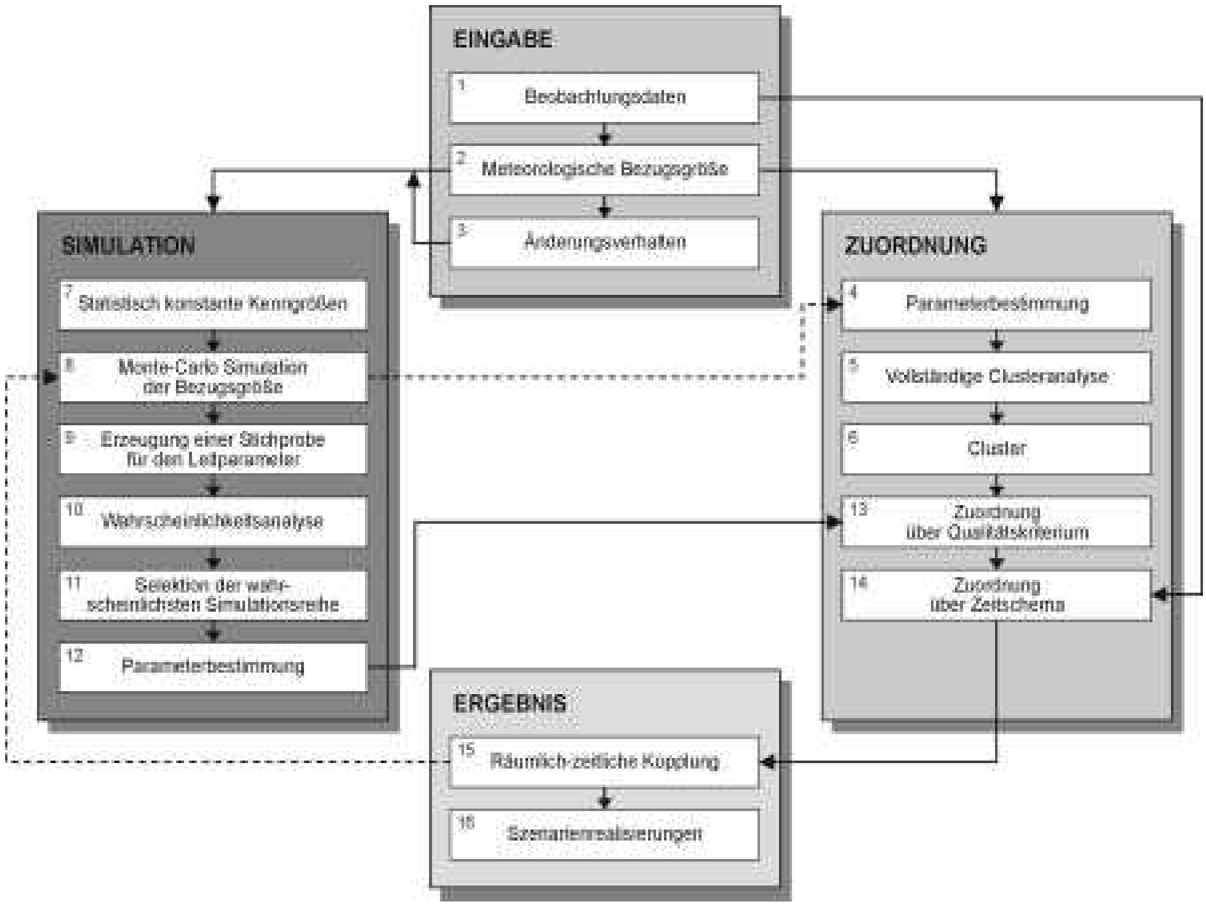

Fig. 1: Scheme of the expanded regional scenario model

3. Statistical scenario calculation

Based on the temperature trend simulated by the GCM ECHAM4/OPYC3 (DKRZ, 2000 with the IPCC A1 emission scenario (IPCC, 2001) 100 realisations of the climate scenario were calculated for the entire Elbe region over the coming 50 years (2001-200). These realisations are now used for investigations on the impacts of climate change in the Elbe river basin.

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GLOWA-DANUBE: INTEGRATIVE TECHNIQUES, SCENARIOS AND STRATEGIES REGARDING GLOBAL CHANGE OF THE WATER CYCLE

W. Mauser, R. Stolz, A. Colgan

Chair for Geography and Geographical Remote Sensing, Dept. of Earth and Environmental Sciences, LMU München, Luisenstr. 37, D-80333 Munich, Germany
w.mauser@iggf.geo.uni-muenchen.de; http://www.glowa-danube.de

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Key words: water cycle, hydrology, Global Change, environmental management

Abstract:
GLOWA-Danube investigates the effects of Global Change on medium sized mountainous watersheds serving developed societies under temperate climate conditions. The Upper Danube catchment is taken as example. GLOWA-Danube includes the development of possible mitigation strategies of unwanted Global Change effects. The aims of GLOWA-Danube are to develop and validate the web-based Global Change Decision-Support-System (GCDSS) DANUBIA as a platform for integration, to develop integrated modeling approaches based on unified modeling techniques and remote sensing, and to deliver alternatives of future development for multinational mountainous watersheds and their forelands under Global Change conditions. The results of the integrative work within GLOWA-Danube of the first year are presented. A common modeling structure was developed and a first proof of concept of DANUBIA was implemented and successfully run on the web. It serves as a test bed for integrating natural and social science models. An overview of the chosen approach, of the architecture of DANUBIA and first results of the DANUBIA demonstrator are given.

GLOWA-Danube:

GLOWA-Danube aims to develop integrative techniques, scenarios and strategies to cope with regional effects of Global Change on the water cycle and its utilization by man in the Upper Danube catchment (A= 77,000 km²). Beyond climate change, the specific vulnerability of mountain environments, conflicts in water utilization, changing population structures, water management technologies and political environments in transboundary water management are water related Global Change issues in the Upper Danube catchment. They will be treated in GLOWA-Danube. The large heterogeneity of the mountain-catchment necessitates a spatially explicit representation of all considered processes within GLOWA-Danube. As main integrative challenge of the first project phase GLOWA-Danube develops and applies the web-based Global Change decision support system (GCDSS) DANUBIA to monitor, analyse and model the impacts of Global Change on nature and society by combining a multitude of environmental, social and economic aspects formulated by the water related stakeholders. DANUBIA will, in a consistent and transferable manner, combine the expertise of all disciplines involved. In the second phase of the project it will be used to improve science in formulating and testing complex scenarios of future development and in measuring the degree of sustainability of different scenarios. DANUBIA will thereby enable to identify most appropriate alternatives in watershed management.
GLOWA-Danube was started in 2001. The members of GLOWA-Danube cover the disciplines meteorology, hydrology, remote sensing, ground water, water resources management, glaciology, economy, agricultural economy, tourism, environmental psychology and computer science.

Development of DANUBIA:

During the first year research was conducted in integrative as well as sectoral fields. Sectoral progress and its relation to integration is documented in the following contributions of each research group. Progress towards integration was achieved in the fields of overall system analysis which led to the design of an integrative modelling infrastructure and a prototype of DANUBIA. It was implemented as version 0.9 and serves as a demonstrator and proof of concept of the final architecture of the GCDSS DANUBIA.

To develop the DANUBIA prototype the following steps were taken:

1. Definition of a common understanding of purpose and architecture of DANUBIA (see Fig.1).
2. Inventory of available disciplinary modelling approaches and definition of a common model architecture and interfaces between disciplines. The raster-based object-oriented proxel-concept was adapted by each group to allow common spatially explicit modelling in each disciplinary field.
3. Definition of a common description of space and time on the basis of a 1-km raster, which was set up in a central data base and filled with the necessary GIS-data.
4. Selection of a common description language to diagrammatically describe the architecture of DANUBIA and the interfaces between the disciplines. The Unified Modelling Language (UML, Booch (1999)) was used for this purpose by all groups.
5. Selection of a suitable programming language to implement the disciplinary model and interfaces on the web in accordance with the formalized UML-description. Java is used for this purpose by all groups, because UML-diagrams can be transformed directly into Java code. Wrappers were also developed, which connect large existing models (e.g. in meteorology) with DANUBIA and thereby make them available for integration.
6. Careful analysis of timing and development of execution sequences for the different models and the implementation of a timing-controller, since all models run in parallel on different computers.
7. Implementation of DANUBIA 0.9 as a demonstrator of the feasibility to integrate models from different disciplines in a web-based environment.

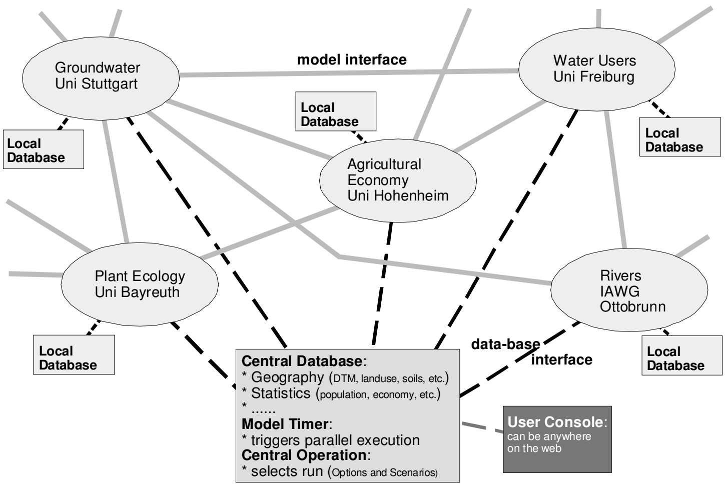


Fig.1: Basic architecture of DANUBIA (a cut-out of the complete model is shown)

The structure of the DANUBIA-network is schematically drawn in Fig.1. It consists of a collection of model-components, which are glued together by model interfaces, which are used to exchange the results for each computation step. Each component runs spatially explicit. The Upper Danube watershed is represented by a rectangular mesh of 1 x 1 km proxel-(*pro*cess-pi*xel*)-objects, which represent the heterogeneities of the catchment. The interfaces between all groups transport data as tables each containing a value for each proxel. They are defined in their form and content via UML and are implemented on the web. In order to synchronize execution all components are hooked up to a central data base. This ensures that all models use the same space, the same basic GIS-data in terms of terrain, land use, statistics. All model-components, which are distributed on the net, are synchronized within a defined timing-sequence. The user console can be accessed by each member and anywhere on the web.

UML was used by all members of GLOWA-Danube to design and further develop an abstract description of DANUBIA and to diagrammatically describe the interfaces between the disciplines. The discussions during set-up of the diagrams showed, that a clear definition of the responsibilities of each group in terms of implementation of interfaces and tasks can be achieved with UML. The UML-diagram of the complete DANUBIA version 0.9 (Jan. 15, 2002) in its most abstract form showing all components and interfaces is given in Fig.2.

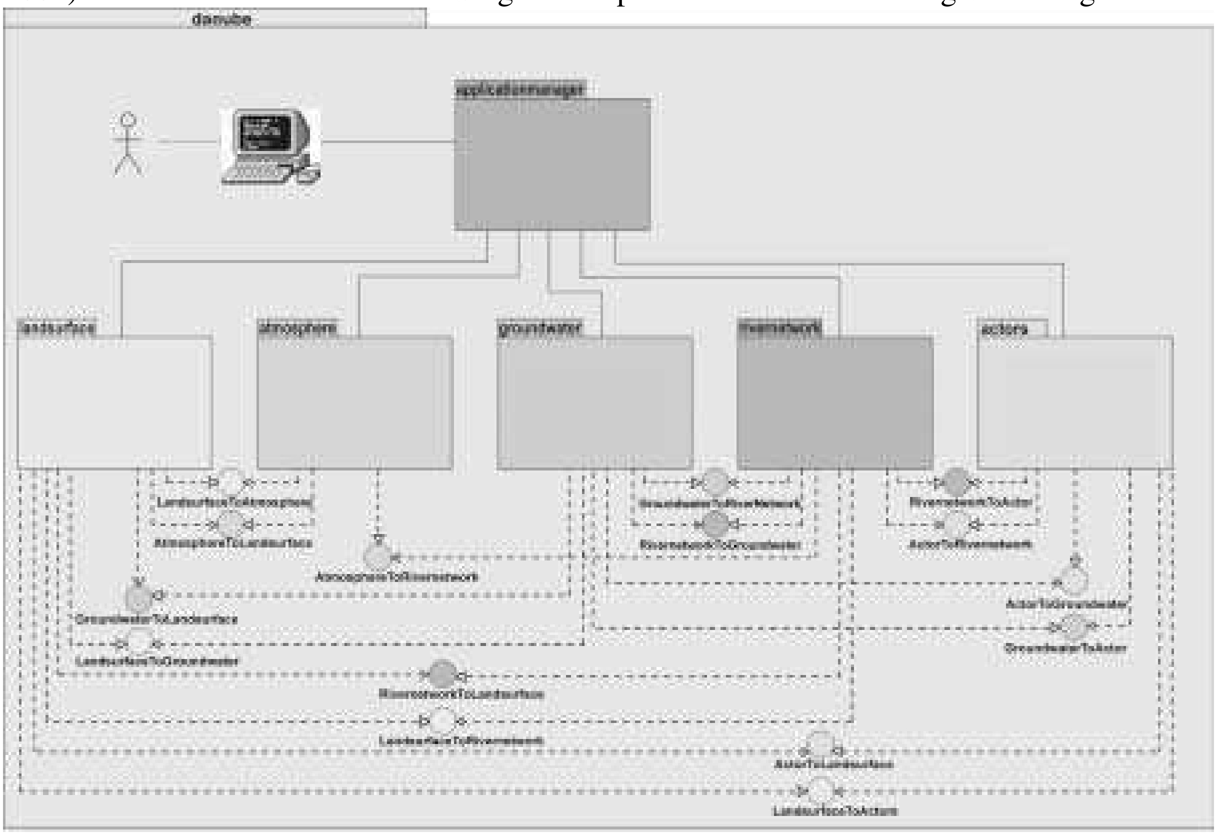
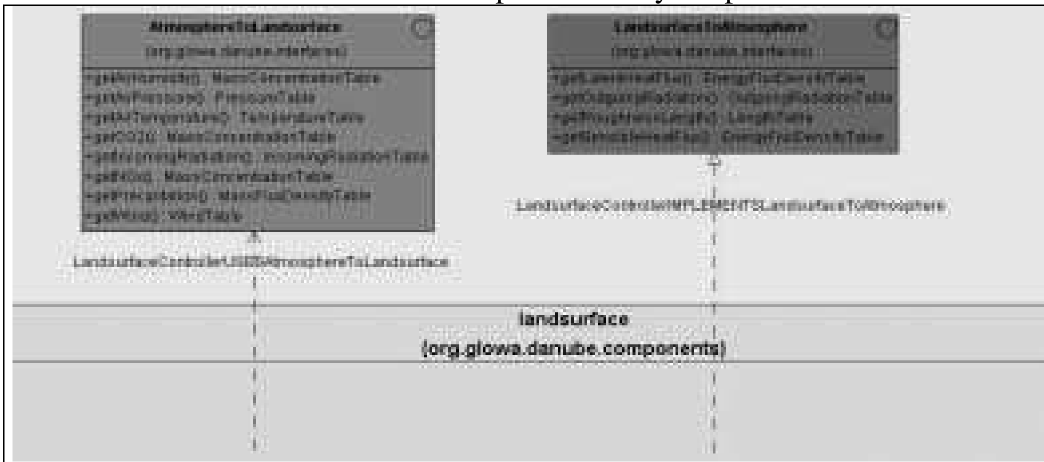


Fig.2: Overview of the UML-diagram of the complete DANUBIA prototype (version 0.9)

Fig.3 shows a cut-out of the interface between the land-surface and the atmosphere as it is defined in DANUBIA 0.9 as an example for a fully coupled interface



Incoming Radiation contains:
- long wave
- short wave
- direct
- diffuse

Outgoing Radiation contains:
- long wave
- short wave

Interfaces show the functions and the units of transported data

Fig.3: Interface between the Atmosphere and Land Surface component of DANUBIA 0.9 described with UML

To improve development, testing and validation of DANUBIA the Bavarian Ministry for Culture and Research together with LMU München on top of the BMBF funding have supplied GLOWA-Danube with the necessary parallel computing power and human resources to run DANUBIA together with all of its components on one parallel computer.

The proxel-objects and the central database

Each participating group is served by DANUBIA with the basic functionality to use the proxel-objects to build up their spatially explicit model-component. Together they describe the watershed. Each basic proxel-object contains location, elevation, neighbours, land-use composition and a sequence number. Routines are supplied by the basic proxel-object to automatically access this information from the central database. The basic proxel-object is then extended by each group member with discipline dependent data and process descriptions to serve the specific purposes of each disciplinary model. Each discipline thereby inherits the basic structure of DANUBIA. This concept, which is schematically drawn in Fig.4, has already proven to be extremely efficient because it allows groups without specific experience in spatial or coupled modelling to easily adapt their models to the spatial structure. Examples together with first results of DANUBIA 0.9 are shown in the following contributions especially from land-surface and environmental psychology.

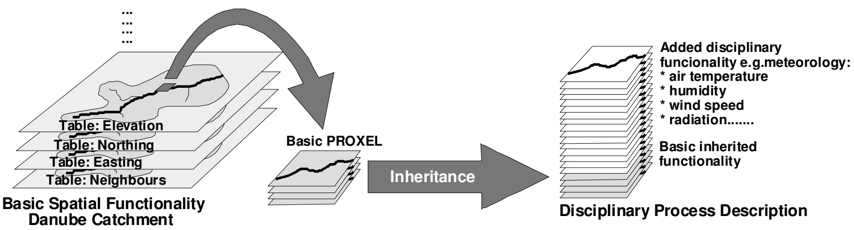


Fig.4: A complex disciplinary proxel inheriting all properties of the basic proxel.

Next Steps within GLOWA-Danube:

The second half of the first project phase will be characterized by the following activities:

- organization of a stakeholder conference to derive design criteria for DANUBIA,
- extension of DANUBIA to incorporate components from all GLOWA-Danube members,
- development of a web-based DANUBIA user interface,
- full coupling between land-surface and atmosphere using the mesoscale model MM5,
- full coupling between land-surface, river-network and groundwater,
- development of a “deep” water user actor and of a “deep” water supply actor,
- development of a farming actor, based on a representative regional farm approach,
- development of a tourist actor, which represents water consumption by tourists,
- development of a proxel-based spatially disaggregated economic model,
- development of simple scenarios including as a first step climate and land use change,
- development of the architecture of a scenario generator within DANUBIA to gather results from its different components, add stakeholder inputs and analyse conflicts.

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Project ID: 07 GWK 04 (research group "Computer Science")

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DANUBIA: A WEB-BASED MODELING AND DECISION SUPPORT SYSTEM FOR INTEGRATIVE GLOBAL CHANGE RESEARCH IN THE UPPER DANUBE BASIN

Rolf Hennicker, Michael Barth, Andreas Kraus, Matthias Ludwig

Institut für Informatik, Ludwig-Maximilians-Universität München, Oettingenstr. 67,
80538 München
hennicke@informatik.uni-muenchen.de

Keywords: integrative simulation, distributed system, object-oriented development, unified modeling language

Abstract:
The ultimate goal of this research group is the development of the integrated decision support system DANUBIA that will be able to simulate water-related issues under ecological and economical aspects and to provide solution scenarios for a sustainable environmental management. DANUBIA is designed as an internet-based platform integrating the distributed simulation models of the participating disciplines such that transdisciplinary effects of mutually dependent processes can be analysed and evaluated. The development of DANUBIA is based on object-oriented software engineering and web engineering methods ([3], [4], [5]) and on the Unified Modeling Language UML [2] which is used by all partners as a common graphical notation for modeling the integrative aspects of the system.
In this chapter we summarise the essential steps to develop the first version of DANUBIA which already connects some selected simulation models of meteorology, landsurface, water research and social sciences. First we describe how the mutually exchanged informations between components are modeled and documented by interfaces. Then we discuss spatial aspects and show how simulation areas are represented. In a next step temporal aspects are considered and the coordination of local model times by a global time controller is described which constitutes the heart of any integrative DANUBIA simulation. Finally, we privide an overview of the architecture of the first DANUBIA implementation which has been realised in Java. This implementation integrates a wrapper framework that we have developed to hide the technical details of network communications for the single components.

Results:
1. *Components and Interfaces:*

The first major task was to clarify the mutual dependencies between the participating disciplines by identifying the kinds of informations to be exchanged between the different simulation models. Each single model plays two roles, acting as a supplier and also as a user of informations. After a careful (partnerwise) analysis of requested and supplied informations a set of interfaces between GLOWA-Danube models has been identified and graphically documented with the UML. Figure 1 shows the form of interface diagrams in the case of three participating models A, B and C which exchange informations through the interfaces AToB, AToC, BToA and CToB. Circles in the upper right corner indicate interfaces and operations of the form getX() describe services that an interface offers. The model which implements an interface (connected to the interface by a dashed line with a solid triangular arrowhead) is responsible for providing the interface informations which can be used by the client model.

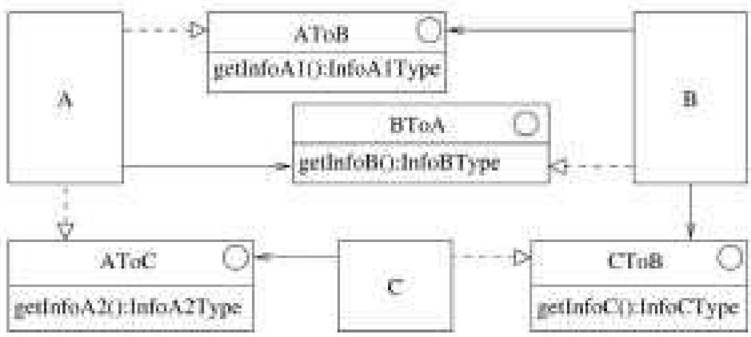

Fig. 1: Interfaces between models

In GLOWA-Danube many different models are involved and diagrams of the above form soon become too complex. To overcome this problem five major components have been identified (*Atmosphere*, *Landsurface*, *Rivernetwork*, *Groundwater* and *Actors*) which group logically related models together. Each component is equipped with a component controller which handles the exchange of informations with other components. The overall network of the GLOWA-Danube components is shown in the abstract of the GLOWA-Danube overview. Each single component contains itself a local network consisting of the models and interfaces inside the component. For instance, the inner structure of the component *Landsurface* is detailled in the abstract of the research group"Landsurface". The kind of decoupling described above is essential for building complex systems. In future research we will focus on formal specification methods and semantics for interacting object-oriented components.

2. *Modeling of Simulation Areas:*

Basically a simulation area is represented by a two dimensional net of proxels (i.e. pocess pixels, see abstract of the GLOWA-Danube overview). Computations are performed proxel-wise. In the DANUBIA system proxels are modeled by objects which have a unique identifier and some basic attributes like e.g. geographical coordinates and elevation. Using the inheritance concept of the object-oriented approach the general proxel class is further specialised to various subclasses (like, for instance, surface proxel or biological proxel) which introduce additional attributes which are relevant for the individual disciplines. The identifier of a proxel is globally valid for the upper Danube Basin and for all subareas for which simulations can be performed. The upper Danube area is modeled by the class SiteMetaData whose attributes reflect the global site description as shown in Figure 2.

Each model is associated with the class SiteMetaData and it administrates an individual proxel table which stores the actual state information for all proxels belonging to the simulation area under consideration. Moreover, each model administrates also a set of export and

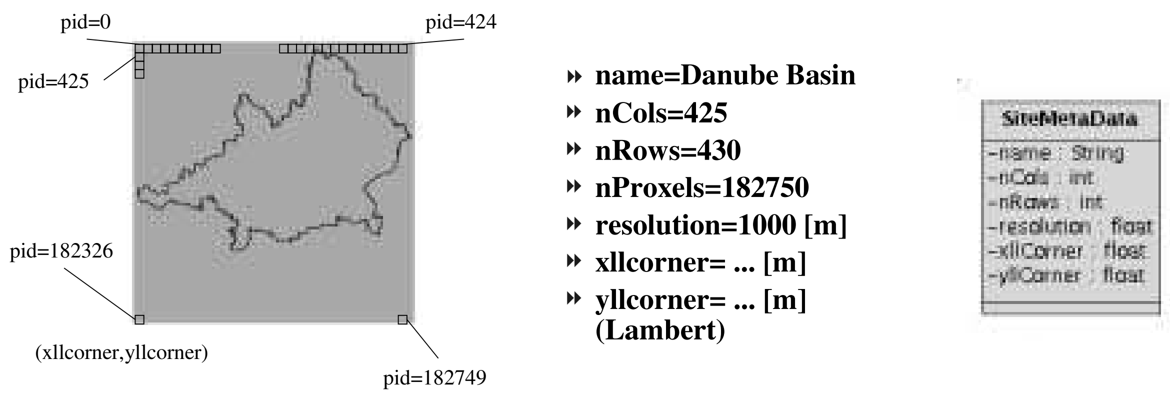

Fig. 2: Site description of the upper Danube Basin

import tables to support the implementation and usage of interfaces as described in the previous section. The essential idea is that an interface offers the requested informations in form of tables which provide the values of interest for all proxels of the simulation area.

3. Controlling Model Times of Distributed Computations:

Any simulation models water-related processes over a specific period of time (days, months or years). For integrative simulations a global time control is necessary which coordinates the single models to work properly together. We have developed and implemented a time controller concept [6] which constitutes the heart of the DANUBIA system. The fundamental task of the time controller is to administrate the overall time period for which an integrated simulation should hold and to control the order in which the single models are repeatedly stimulated to perform their next computation step. In particular, the time controler solves the following major issues:

a) Each simulation model has an individual time step (model time) for which computations are periodically executed (ranging from minutes, like in meteorology, to months, like in social sciences).

b) Values that are accessed through interfaces must be in a consistent state and must be valid with respect to the global simulation time.

For a precise analysis of the coordination of distributed models the state model shown in Figure 3 has been developed which shows the general scheme of state transitions performed by each of the GLOWA-Danube components.

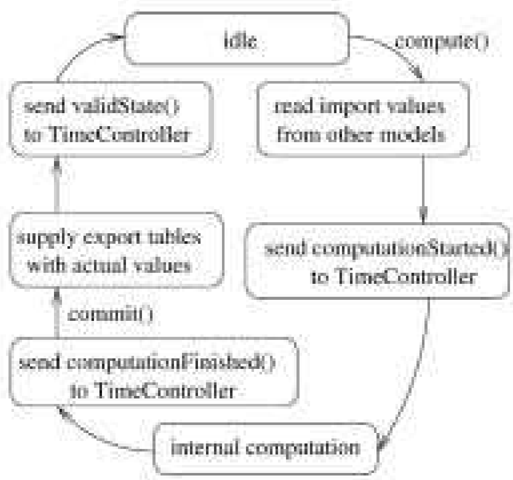

Fig. 3: State model for distributed simulations

The signal compute() is sent from the time controller to the model in order to initiate the next computation step. To ensure consistency of values it is essential that a model can only access values from other models if these models do not supply their export tables at the same time. This condition is controlled by the time controller who explicitly sends a commit() signal if a model is allowed to transfer new values to its export table.

4. Architecture of DANUBIA 0.9:

The concepts described above have been implemented in version 0.9 of DANUBIA where some selected models of meteorology, landsurface, water research and social sciences are integrated. In the next step DANUBIA 0.9. will be extended to integrate all GLOWA-Danube models. The implementation language is Java and the network communication is realised by Java's RMI technology Figure 4 gives an overview of the system architecture in the case of two cooperating models A and B. For each single model the network communication is hidden by a corresponding wrapper [1] which simulates each remote interface by a corresponding proxy that resides on the client side. The bold dashed lines indicate network borders of local systems. The essential task of the developer of an individual simulation model is the implementation of the methods compute() (called by the time controller via its model client) and init() which is called by the model manager when a simulation is started. During initialization the model accesses the central DABUBIA database for retrieving site desriptions which must be consistent for all participating models. In the next step a web-based user interface for DANUBIA will be constructed using novel Web Engineering methods [4], [5]. These methods will be further elaborated to allow semi-automatic generations of Web applications.

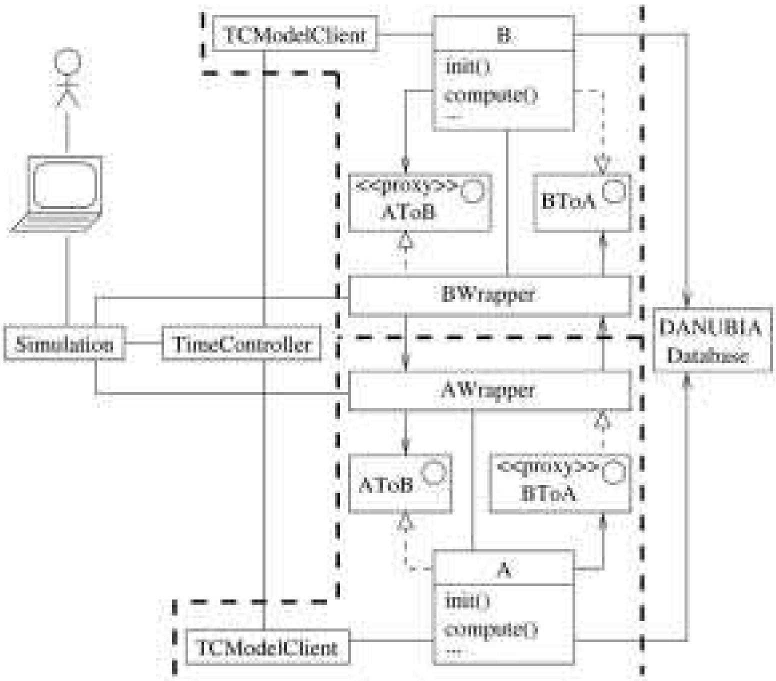

Fig. 4: System architecture with time controller and network wrappers

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MODELLING FLUXES OF WATER, ENERGY AND MATTER AT THE LAND SURFACE

R. Ludwig, M. Braun, S. Niemeyer, M. Probeck, D. Reichert and W. Mauser
(Research group „Hydrology / Remote Sensing")

Chair for Geography and Geographical Remote Sensing, University of Munich
ralf.ludwig@lmu.de, http://www.geographie.uni-muenchen.de

M. Reichstein, A. Bobeva, Q. Wang, N. Dinh, E. Falge and J. Tenhunen
(Research group „Plant Ecology")

Department of Plant Ecology, University of Bayreuth, D-95440 Bayreuth
markus.reichstein@uni-bayreuth.de; http://www.uni-bayreuth.de

H. Escher-Vetter[1] and M. Kuhn[2]
(Research group „Glaciology")

[1] Commission for Glaciology, Bavarian Academy of Sciences, Munich
[2] Institute for Meteorology and Geophysics, University of Innsbruck
Heidi.Escher@LRZ.BADW-Muenchen.de; http://www.glaziologie.de

Keywords: *Landsurface-object*, Hydrology, Remote Sensing, Plant Ecology, Glaciology

Abstract

The research group "Landsurface" merges the specific expertise of the project partners "Hydrology / Remote Sensing", "Plant Ecology" and "Glaciology" in order to integratively describe the physical and biological characteristics of landsurface processes. A model framework has been created and implemented to directly link, combine and extend existing process descriptions. The organisational structure of DANUBIA requires an explicit hierarchy of sub-models. In order to avoid redundance and thus ambiguous results the participating sub-models have been partially decomposed and restructured to allow for concise and efficient process representation. Therefore, the "Landsurface-object" comprises the components "RadiationBalance", "Snow", "Surface", "Biological" and "Soil", which are each represented by process-based sub-models. The algorithmic basis to simulate the important processes is adopted from existing models, such as PROMET-V [1] (for RadiationBalance, Surface, Soil), $PROXEL_{NEE}$ [2] and $BIOME_{BGC}$ [3] (for Biological) and PEV-SD [4] (for Snow). The definition of interfaces as well as the generation of basic Java-Code for the "Landsurface-object" was conducted using the Unified Modeling Language UML. The current stage of model development and implementation in the framework of DANUBIA is described. Disciplinary research activities of the participating work-groups are adiitionaly summarized.

Model Concept and Implementation:

The development of the DANUBIA system requires the supply of functional objects to generate and then validate the coupling and interacting of system components. Due to the commonality in objects of interest, the project partners "Hydrology/Remote Sensing" (Niemeyer/Ludwig/Mauser), "Plant Ecology" (Reichstein/Tenhunen) and "Glaciology" (Escher-Vetter/Kuhn) have in close cooperation combined their existing expertise in an integrated description of interdependent fluxes of energy, water and matter at the land surface. These processes are directly coupled and their interactions are examined within the framework of a complex system, namely the *Landsurface-object*. The purpose of this object is to prevent multiple calculations of the same processes in the simulations, establishing an orchestrated framework which appears as a single encapsulated component to interface with the adjacent objects *Atmosphere*, *Rivernetwork*, *Groundwater* and *Actors*. A common analysis of algorithms indicated, that separate building blocks of the available models could be used, but would be implemented with newly restructured interactions. The DANUBIA synchronisation scheme requires an orientation to typical process sequences and related feedbacks in nature, such that each process component is individually computed at the specific locations in the distributed model. Therefore, traditional simulation sequences are rearranged in the *Landsurface-object*, which now comprises the components "RadiationBalance", "Snow", "Surface", "Biological" and "Soil" (Fig. 1), each represented by process-based sub-models. In order to maintain individual responsibilities and avoid inconsistencies, the interdependent processes communicate directly within the *Landsurface-object and* via the WWW. The new components are respectively designed according to leading competence: The research group "Hydrology / Remote Sensing" is in charge of the development of the components "RadiationBalance", "Surface" (assisted by "Glaciology") and "Soil"; "Biological" is under construction by "Plant Ecology" and "Snow" will be implemented by "Glaciology". The object-oriented structure of the *Landsurface-object* allows for parallel evaluations with those components not immediately required at particular locations (such as "Biological" and "Snow") and, therby, reduces unneccessary inertness in the network-distributed system. For the implementation of algorithms in newly generated Java source code, a variety of already existing models are reused and have been refined in the process. The division of competence is summarised in Table 1:

Table 1: Assignment of competence to the "Landsurface"-components

"Landsurface" component	***performs the calculation of***
RadiationBalance	radiation balance of all surfaces, phase of precipitation, momentum flux, stacked distribution of meteorological parameters in the canopy
Snow	accumulation and depletion of snowpack, energy balance of snowpack, nitrogen deposition in the snowpack, snow meltwater production
Surface	interception and evaporation, effective precipitation, energy balance of all snow-free surfaces, nitrogen deposition at the land surface
Biological	stomatal and canopy conductance, transpiration, photosynthesis and carbon gain, soil CO2 efflux, N-uptake, N-cycling, ecosystem structural change, plant growth, harvest of usable products
Soil	stacked soil water fluxes (infiltration, exfiltration, groundwater recharge, capillary rise), soil temperature profile, soil nitrogen balance, runoff generation, lateral flow

The spatial concept of DANUBIA has been developed in close cooperation with the research group "Computer Science". It regulates the spatial management of proxels by means of so-called ProxelTables (see "Computer Science"-abstract), which enable an exchange of spatial parameters in terms of DataTables. Each proxel is identically equipped with a set of common parameters to define its location in space, its adjacencies as well as some parameters invariable during run-time, such as topography, landuse etc., from which all further calculations can unambiguously proceed. The computation of the single terms (Table 1) demands a concise internal definition of model sequence. While the *Landsurface-object* initializes with an hourly timestep at the DANUBIA TimeController for communication with its environment, the internal process chain has to be finer resolved to assure short-term response of data and parameters. Therefore, all components of the *Landsurface-object* are processed within the model timestep and hence fed back to external data input with a maximum delay of one (model-) hour.

The Unified Modeling Language UML has been excessively utilised to define the interfaces between the “Landsurface” components and to organize the exchange of data and parameters with the neighbouring objects *Atmosphere*, *RiverNetwork*, *Groundwater* and *Actors* via the *LandsurfaceController-object*.

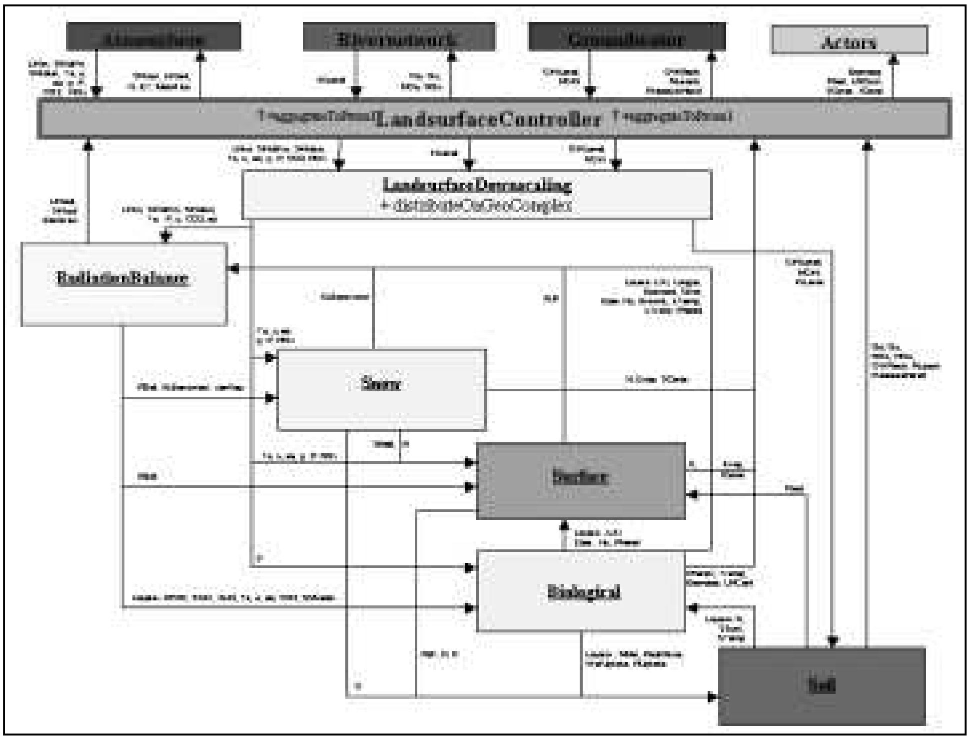

Fig. 1: Conception of the *Landsurface-object* in DANUBIA

In addition to an explicit structure, UML provides the opportunity to generate Java-source code from its class diagramms. This function has been used to build the basic code framework of the *Landsurface-object*, which is currently filled with functional content based on already existing, well tested model components taken from PROMET-V (1), $PROXEL_{NEE}$ (2), $BIOME_{BGC}$ (3) and PEV-SD (4). All sub-components of the *Landsurface-object* have been fully transferred into a DANUBIA-compatible structure and are currently extended to executable DANUBIA components. The embedding in an outer wrapper as well as the connection to the DANUBIA TimeController is as a prototype completed, so that a preliminary runtime-version of the *Landsurface-object* in the DANUBIA (version 0.9) framework will be available.by the end of March 2002.

Sectoral work:
The development of the *“Landsurface-Object”* is accompanied by various sectoral research activities of the participating partners, which are briefly summarized as follows:

1) Research group “Hydrology / Remote Sensing”

- The *Landsurface-object*-concept has been developed and implemented. The spatial conception of DANUBIA has been developed in collaboration with “Computer Science”.
- Routines describing the radiation balance of surfaces, the soil water movement and runoff production have been re-written and implemented in DANUBIA-compatible Java code.
- The meteorological sub-module of PROMET-V (1), interpolating fields of meteorological parameters from stations networks, has been fully transferred to Java to preliminarily provide meteorological information for the testing of the DANUBIA prototype. The generated

source code has been made available to the research group “Atmosphere” to serve as a starting point for further scientific developments.

- Remote sensing information is used as a source of input- and validation data for multiscale modeling approaches. Java-based software has been developed to geometrically correct MODIS imagery. Spatial maps of Leaf Area Index have been derived from MODIS NDVI and for the Upper Danube catchment, using land use dependent regression functions implemented in PROMET-V [1]. Results show considerable improvement of plausibility, especially for arable land and pasture, when compared to MODIS LAI products.

  An enhanced method of multiemporal spectral unmixing has been developed to derive subscale information on land use from NOAA-AVHRR imagery. A multitemporal image stack is used to create fraction images, which imply the areal fraction of specific land use types within each proxel. A *fuzzy-logic* based technique has been established to analyse the *geo-factors* elevation, slope, climate, and soil types to provide a probability matrix for each proxel according to the *Minimum Factor Principle*. This method reasonably reduces the number of theoretically available endmembers for each proxel. Results of this successfully validated approach have been made available to all project partners via the GLOWA-Danube database and serves as the principle land use dataset for the model implementation of DANUBIA 0.9.

- The concept of “*Geo-complexes*” is currently developed. Its objective is to provide equivalent process descriptions across scales (microscale to 1-km² proxel) while reducing spatial heterogeneity to its substantial hydrologic information. Each proxel is described as a composition of diverse homogeneous units of vegetation, soil and topography, for which all fluxes can be indidvidually determined. Once the areal fraction of each unit within a proxel is known, these fluxes can be aggregated accordingly. A first approach in modeling the water fluxes using subscale land use information (derived from spectral unmixing) showed a significant improvement of results in terms of modelled water balance and runoff production and is considered a valid proof-of-concept.

2) Research group “Plant Ecology”

The subproject quantifies 1) ecosystem transpiration, net carbon dioxide exchange, and N-uptake, and 2) the time dependent production of biomass (including harvested products).

- Differentiation in the water use and biomass production of landscapes is a function of the variation in gas exchange characteristics exhibited within the landscape ecosystem mosaic. Stomatal regulation, transpiration and net ecosystem carbon dioxide exchange were parameterised in submodels to correctly describe ecosystem physiology of hay production meadows, wheat fields, and lowland deciduous, mixed and coniferous forests at intensive study sites. Ongoing work during 2002 and 2003 will extend these parameter sets to include mountain meadows and forests, barley, sugar beet, maize and wetlands.
- Routines describing water use and carbon gain by the vegetation have been re-written and implemented in Java in a form compatible with the *Landsurface-object* in DANUBIA.
- Utilization of parameter sets for ecosystem gas exchange at the level of the Danube Catchment require that spatial and temporal patterns in ecosystem structural change, i.e., in Leaf Area Index, are defined. Direct comparisons of measured LAI changes, AVHRR-NDVI signals and MODIS LAI are being carried out at lowland intensive study sites. Initial maps for forest LAI along elevation gradients in the Berchtesgaden National Park have been compiled from forest inventory data for similar comparisons. Extrapolation to the entire catchment will be undertaken with “Hydrology / Remote Sensing”.
- The subproject relates ecosystem gas exchange to the production of biomass and socially desirable plant products, i.e., wood and crop production. The coupling of fluxes with biogeochemistry in the Danube Catchment requires that routines of the precursor model $BIOME_{BGC}$ be written in Java, be compatible with the *Landsurface-object*, but additionally

be compatible with process observations at intensive study sites and along climate gradients in the Alps. Current foci with respect to modification of the process descriptions are on internal plant carbon allocation (such that carbon gained in the physiology routines effect a correct time dependent change in LAI) and on root development in a multi-layered soil ($BIOME_{BGC}$ has only a single soil compartment). Forest inventory studies in the Berchtesgaden National Park permit testing of the new model along elevation gradients, while the primary focus in lowland areas together with the Subproject " Agroecosystems" is on agricultural production.

3) Research group "Glaciology"

- The determination of model parameters for the "Snow" component of the *Landsurface-object* is performed with the proxel-based energy balance model PEV-SD (4), originally developed to simulate snow and ice meltwater production and runoff in heavily glacierized catchments. The implementation of PEV-SD as a component for the DANUBIA system requires significant rearrangements: runoff simulation is excluded, while snow accumulation and meltwater production from snow and ice is modelled for the whole catchment area of GLOWA-Danube. This enlargement requires major adjustments of regionalisation methods to describe the small-scale heterogeneities in a more appropriate way. Therefore, the parameterisations for the turbulent fluxes as well as for the ground heat flux have to be adapted to the varying surface structures and especially to the unstable layering of the atmosphere over only partly snow-covered surfaces.
- First results were obtained for a 165 km² catchment in the Ötztal Alps with a glacierisation of 38%. The modelling period comprised nearly three years, the timestep was one hour, the spatial scale 100 m. Vertical gradients of air temperature, humidity, pressure, wind velocity and precipitation data as recorded at a meteorological-hydrological station in the upper part of the catchment were applied as in PEV-SD. As the shortwave radiation absorption delivers the largest energy amount for the melting of snow and ice, the temporal and spatial development of the albedo played the most important part in this evaluation. The results show a comparatively good agreement in the glacier region, they deteriorate in the lower parts where snow and ice do not prevail during the whole year. This is partly due to the incorrect precipitation regionalisation, partly to insufficient parameterisation schemes of the turbulent fluxes, as mentioned above.
- The main aim of the further work will therefore concentrate on the refinement and testing of the parameterisation schemes for the "Snow" component. A digital representation of the actual glacier distribution, which is under construction right now, will improve the source data of land cover in the GLOWA-Danube catchment.

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INTERACTION BETWEEN PRECIPITATION AND LANDSURFACE

A. Pfeiffer[1], B. Früh[2], J.W. Schipper[1], J. Egger[1], V. Wirth[2]

[1] Meteorological Institute, Ludwig-Maximilians-University, Theresienstr.37, 80333 Munich, a.pfeiffer@lrz.uni-muenchen.de; www.meteo.physik.uni-muenchen.de
[2] Institute for Atmospheric Physics, Johannes Gutenberg-University, Becherweg 21, 55099 Mainz, frueh@uni-mainz.de; www.uni-mainz.de/FB/Physik/IPA/

Keywords: Atmosphere-object, meteorological observations, atmospheric simulation (MM5), landsurface-atmosphere interaction, downscaling

Abstract:
Using German (DWD) and Austrian (ZAMG) measurements, the mesoscale model MM5 and satellite data (see research group "Rainfall Retrieval"), the "Atmosphere"-group has established the exchange of numerous parameters, which are relevant to GLOWA. After interpolating, parameters will be exchanged at a height of 2 m above land surface. The exchange of parameters between "Atmosphere" and other GLOWA disciplines takes place over the 'AtmosphereController'. This implies a more uniform exchange, which is of great benefit to the user. In order to decrease the simulation time, MM5 operates on a resolution of 15x15 km. The output then is brought down to 1x1 km (as decided within GLOWA) by statistical downscaling. Additionally, a factor is produced to correct the downscaling for the higher resolved orography.

Results:
For the data exchange of the meteorological parameters, routine measurements were employed from the standard network of the German (Deutscher Wetterdienst, Offenbach, DWD) and the Austrian Weather Service (Zentralanstalt für Meteorologie und Geodynamik, Vienna, ZAMG).
The mesoscale model MM5 (2 and 3) will be used for the atmospherical simulations within the DANUBIA. The model is equipped with several schemes for convective parameterisation. For the interaction between the atmosphere and the surface, MM5 has additional schemes to parameterise the boundary layer. For a realistic land-atmosphere exchange, the model is predefined for GLOWA with a particular high resolution in the vertical. Therefore, the lowest model level is at 16 m, which gives information at a height of 8 m. As many parameters are exchanged at an even lower height (e.g. 2 m), a new routine interpolates to the necessary heights.
A standard MM5 output contains much more parameters than needed in GLOWA. For that reason, MM5 is modified to give the required fields as output only. Because the exchange within GLOWA requires some additional data, the model is extended to give those parameters as output, too.
The interfaces between the different subgroups of "Atmosphere" (AtmoSat, AtmoMM5 and AtmoDWD) are organised internally and are in principle invisible to a user. The communication with other disciplines of GLOWA is controlled by the 'AtmosphereController'. This makes the source of data irrelevant to a user, which means that the data can be imported easily without any source dependent formatting. All interfaces have been designed using the Unified Modeling Language UML and will be coded in Java complying with the concept of a geo-

graphical representation of the area of interest by a net of proxels (see research group "Computer Science"). The parameters, which have been chosen in agreement with the "Landsurface"- and the "Rivernetwork"- group to be exported by "Atmosphere" are: temperature, humidity, air pressure, wind, several radiation components and precipitation. Not simulated yet, but merely measured are CO_2 and NO_x.
In future, "Atmosphere" will also receive data as input for the MM5 model from other disciplines, first of all from "Landsurface". The basic data set that will be imported into MM5 comprises: the fluxes of sensible heat, latent heat and of the momentum between the surface/vegetation and the atmosphere, and the outgoing radiation (i.e. the upward radiation from the surface) To do so the MM5 is being modified in order to substitute the so far used parameterisation schemes (e.g. for the soil conditions) with the more sophisticated output of specialised models (e.g. the hydrological model PROMET V of "Landsurface"). In this way a two-way interactive coupling of the *Atmosphere-* and *Landsurface-object* will be achieved. Eventually simulations of MM5 could even be influenced - indirectly via the *Landsurface* module - by political, psychological and economical effects. This will generally make the model interactive, which is one of the main goals of the GLOWA project.
MM5 data output typically has a resolution of 15x15 km. Within GLOWA, the decision has been made that all data will have a resolution of 1x1 km. Instead of forcing the model into that resolution (which would increase the simulation time enormously), a special routine is being developed to downscale the output of MM5 as realistically as possible. For the precipitation, the routine converts the measurements from all stations to daily and monthly averages and normalises the daily averages to the monthly averages. In case of missing observations, these will be replaced by measurements of best correlated stations nearby. The result is the 'daily climatological measurements' for each station. Then, the so-called Shepard algorithm (4) interpolates the results to an equidistant 2-dimensional grid with a resolution of 1x1 km. In this way, the numerical inaccuracy is diminished (5). As a last step, the 2-dimensional grid has to be corrected to a higher resolved orography. Therefore, it is connected to the PRISM climatology (Precipitation-elevation Regression on Independent Slopes Model) delivered by Frei (priv. comm., 2002) and described by Daly (1). An equivalent routine concerning downscaling is described by Widmann (5, 6). The 'climatological measurements' (1x1 km) described above are compared with a climatology run of MM5 (15x15 km), to get an orography correction factor. During an operational MM5 run, the 15x15 km model output is automatically multiplied by the correction factor to obtain the most reliable results.

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RETRIEVAL OF CONVECTIVE PRECIPITATION IN THE DANUBE COLLECTION AREA BY MEANS OF METEOSAT SECOND GENERATION (MSG) AND METEOSAT

Th. Nauß, Ch. Reudenbach, J. Bendix

LCRS, Department of Geography, Philipps-Universität, Deutschhausstr. 10, 35032 Marburg
Bendix@mailer.uni-marburg.de; http://lcrs.geographie.uni-marburg.de

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Key Words: satellite rainfall retrieval, convective, advective, precipitation, effective radius

Abstract:
The integrative aim of this project is to make available high-resolution rainfall information via the DANUBIA Atmosphere Controller interface to other groups – especially for spatio-temporal highly variable convective induced precipitation which can not be sufficiently simulate by the MM5 model yet (see abstract research group "Meteorology"). Primarily, four parallel approaches have been pursued thus far: (1) the implementation of the FORTRAN-based Enhanced Convective Stratiform Technique (ECST) in the online DANUBIA system by means of a JAVA wrapper, (2) retrieval of the effective droplet radius with two different tri-spectral approaches for both day-time data [1] and night-time data [2], (3) the detailed derivation of cloud types with respect to their actual lifecycle phase as a function of changing effective droplet radius with cloud-top temperature [3], and (4) the retrieval of advective-stratiform-induced rainfall with respect to the complex phenomenon found in the northern Alps downward slope. Preliminary results are very promising; therefore, a primary version of the Advanced Convective Stratiform Technique (ACST) could be realized by the year 2002.

Results:
Since the launch of the MSG-SEVIRI System was postponed and is now scheduled for mid-2002, Meteosat, NOAA-AVHRR, and TERRA-MODIS data have been used for research work until now with respect to the spectral properties of the MSG-SEVIRI System.
The operational retrieval algorithm of the ECST for Meteosat datasets was locally implemented in the DANUBIA decision support system using a Java wrapper. Based on the ECST, further research was and will be conducted to derive more accurate rainfall rates as a function of cloud-top temperature, effective cloud droplet radius, cloud type, and the lifecycle of cloud systems by means of the new Meteosat Second-Generation (MSG) System established within the ACST. The implementation of a 3-D cloud model compatible with the upper Danube collection area into the ACST will further improve the quality of the retrieved rainfall information by allocating specific rainfall rates to specific precipitation types and stream directions. Finally, the ECST will be replaced by the ACST without necessary changes of the Unified Modeling Language (UML) structure because of the Java wrapper solution.

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STREAMFLOW ROUTING AND TRANSPORT MODELING IN THE CHANNEL NETWORK OF THE UPPER DANUBE

W. Willems, S. Mendez-Rueda, K. Stricker

Institute of Water Resources and Geoinformatics (IAWG), Alte Landstrasse 12-14, 85521 Ottobrunn, willems@iawg.de; www.iawg.de

Keywords: streamflow routing, diffusion analogy, regime theory, water quality constituents

Abstract
Procedures for streamflow routing and transport modeling in the Upper Danube Catchment and its tributaries are described. One-dimensional streamflow routing is done by the so called diffusion analogy. The achievements of this simplified hydraulic model are compared with the results of a complex hydrodynamic model. The parameters for the diffusion analogy are found with the help of the regime theory. Interactions and the movement of water-quality constituents are quantified by one-dimensional convective-diffusion coupled equations with reaction kinetics. The data requirements for the streamflow routing and transport modeling components are described.

Results
1. Purpose
Within the framework of GLOWA-Danube, the IAWG research group "Surface Waters" ("Oberirdische Gewässer") routes the discharge produced at the land surface and in the upper layers of the soil through the river network of the Upper Danube Catchment. In addition, the movement and interaction of selected constituents within the water is quantified. In the framework of the GLOWA-Danube the research group represents the "*Rivernetwork*-object". The following variables are computed: the hydraulic parameters discharge, stage, and velocity, the physical property water temperature, the constituents nitrate and dissolved oxygen and the parameter biological oxygen demand.

2. Modeling principles
Streamflow modeling is based on simplifications of the Saint-Venant equations, where acceleration terms are neglected (Brosherars et al. 2001). This modeling concept which is called diffusion analogy is applicable when backwater effects are not significant and flow reversals do not occur. Because of the topographic character of the Upper Danube Catchment, the validity of this assumption can be expected to be fulfilled for the majority of the river network.
In order to test the performance of the simplified hydraulic model, a comparison was made between calculation results of diffusion analogy and a complex two dimensional hydrodynamic model that implements a numerical solution of the shallow water equations. The test was made for two strongly regulated rivers within the Upper Danube Catchment. It could be shown that the model performance of the diffusion analogy was comparable to that of the complex model.
Two parameters are needed by the diffusion analogy for each subreach: the wave celerity parameter c_k ("speed of moving wave") and the wave attenuation parameter D_f ("diffusion of moving wave").

The water quality model which is used here consists of algorithms to route any number of interacting constituents through a system of one-dimensional channels. The model solves the one-dimensional convective-diffusion equation with reaction kinetics. It was decided here to use algorithms implemented in the freely available water quality modeling systems WASP5 (Ambrose et al., 1993) and BLTM (Jobson / Schoellhamer 1987) in order to utilize the advantages of both modeling systems.

3. Coupling of models

The Unified Modeling Language UML has been utilized to define the interfaces between the "*Rivernetwork*-object" and the objects "*Landsurface*", "*Groundwater*" and "*Actors*" (see also research groups "Landsurface", "Groundwater", and "Actors"). Some of the simulated data of the streamflow routing will be delivered to the *Groundwater*-object and to the *Landsurface*-object. The *Actors*-object gets all the simulated data about the water quality.

In order to compute the bi-directional exchange of discharge between streamflow and the groundwater aquifer, a leakage formula is used which is based on the following parameters: the hydraulic conductivity of the streambed, the length of a stream reach in hydraulic connection with the aquifer cell, the average width of stream along the aquifer cell, the head of aquifer in the cell, the average depth of a stream in the subreach crossing the aquifer cell, the average elevation of streambed as it crosses the aquifer cell and the thickness of the streambed (Jobson et al., 1999). It has not yet been decided how to quantify these parameters in a way that is appropriate to the catchment size of the Upper Danube and the data availability.

The coupling of the streamflow routing model and the *Landsurface*-object is done in a straightforward manner by adding the overland discharge produced by the *Landsurface*-object at every proxel which is defined to be a "river proxel". Flow is considered to be unidirectional from the land surface to the stream.

4. Implementation within the GLOWA-Danube-framework

All model components which are provided by the research group "Surface Waters" are implemented in Fortran. Much work had to be done in order to prepare the sources in such a manner that they may be integrated in the Java-Framework of GLOWA-Danube. In the case of the hydraulic model, the implementation is completed, so the *Rivernetwork*-object could be integrated into the first prototype of the GLOWA-Danube framework, version 0.9.

5. Parameter models and data requirements

The application of models is only possible when they can be parameterized in a consistent and physical meaningful manner. Because of the fact that the GLOWA-Danube framework is proxel-based, the parameters have to be provided for every proxel which is defined to be a "river proxel" within the Upper Danube Catchment.

We use the so called regime theory for providing the model parameters for the hydraulic model (Luna / Maddock 1963). Assuming the validity of this theory, the two parameters c_k and D_f of the diffusion analogy are derived from the hydraulic geometry coefficients for area and top-width. A procedure to derive the hydraulic geometry coefficients by using a digital elevation model has been prepared as draft and is now being implemented within a geographical information system. Further on, an algorithm is under development which delivers information about the network structure inherent in the digital elevation model in order to build the control file for the streamflow routing model. For parameterization of the hydraulic model, the minimal data demand consists of a digital elevation model and measured time series of discharge at different gauges in the Upper Danube Catchment. In order to parameterize those river segments more realistically, where river constructions have taken place, an additional demand for data in form of discharge–stage relationships, location and hydraulic ca-

pacities of weirs and dams as well as cross sections are necessary. Much of that data has already been acquired.
The challenge of the water quality modeling is to find an acceptable solution for the parameterization of the model at the scale of the Upper Danube Catchment because some of the parameters that entered into the modeling can hardly be measured in nature or are very difficult to obtain. As a first guess, parameters are taken from literature (EPA, 1985). Depending on the availability of measured time series, calibration of model parameters will be conducted. Measured time series for a small number of gauges along the main streams are currently available.

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GROUNDWATER MANAGEMENT AND WATER SUPPLY

R. Barthel, J. Wolf, D. Nickel, V. Rojanschi, C. Schmid, J. Braun

Lehrstuhl für Hydraulik und Grundwasser, Universität Stuttgart, Pfaffenwaldring 61, 70550 Stuttgart
juergen.braun@iws.uni-stuttgart.de; http://www.iws.uni-stuttgart.de

Keywords: Finite Difference Model, Geo-statistics, Groundwater Flow, Hydrogeological Conceptual Model, Nitrogen Transport Model, Up-scaling, Know-how Transfer

Abstract:
*The task of the research group "Groundwater" is to model groundwater flow and nitrate transport within the upper Danube catchment basin up to the Passau gauging station. The particular challenge lies in the modelling of groundwater flow and substance transport for a large grid fixed to 1000*1000 m and in the constant exchange of in- and output data with the other research groups (parallel calculations). The proxel architecture of DANUBIA (fixed cell size), necessary to ensure communication between the different disciplines, requires the development of new up-scaling methods to reproduce soil heterogeneity and geo-hydraulic boundary conditions in order to simulate groundwater flow and substance transport without an adaptation of the grid. Parallel to the development of the up-scaling methods, emphasis is placed on the procurement of data for a drainage area of this magnitude (covering approximately 77.000 km², this is the largest modelling endeavour yet undertaken in Germany). Geostatistical methods are utilised and if necessary enhanced to describe the subsurface in areas that are not yet or only poorly investigated. International students are actively integrated in this research in order to ensure know-how transfer to developing and emerging countries.*
Parallel to the development of the flow and transport model its integration in the structure of DANUBIA is pursued. Hence, all models and underlying databases must be designed to enable the control of input and output data, spatial correlation and timing through central controllers and databases.

Results:
The Groundwater object is primarily based on the numerical flow and transport models MODFLOW and MT3D, respectively. The distinct feature, however, is that the modules are linked directly to the other DANUBIA objects Landsurface, Surfacewater and Actors.
Based on the data currently available for the catchment area, a first conceptual hydrogeological model has been conceived as a prerequisite for the development of the numerical model. The conceptual model consists of four layers, comprising the units "Malm Karst", "upper Tertiary Molasse", "lower Tertiary Molasse" and "Quaternary" (Fig. 1). The units "upper" and "lower" Molasse are for the most part synthetically defined and only then oriented on the lithostratigraphic units where this is stringently required by the geological situation. The upper Tertiary unit is a 50m thick layer, within which the important local structures can be modelled independent of the properties of the subjacent Molasse. The Quaternary deposit is for the most part defined by local water permeable structures (valley aquifers, alluvial gravel plains). The hydrostratigraphical units subjacent to the Malm will not be considered explicitly, as here groundwater exchanges take place which are negligible for GLOWA. Therefore the base of the Jura aquifer constitutes the model basis.
In the alpine section of the model area and the Palaeozoic Basement in Northeast Bavaria, local hydraulically disconnected aquifers predominate. Since they are too small to be mod-

elled on the predefined grid size, these areas are excluded from the groundwater model. Instead, a boundary which allows temporally-variable inflows will be drawn along these sections. The task of quantifying such boundary inflows into the model area is still under investigation.

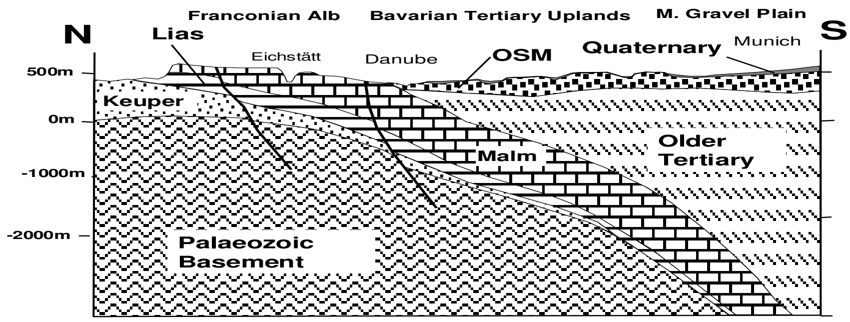

Fig. 1: Schematic geological north-south cross-section through the drainage area of the Danube (Barthel et al. 2002)

Parallel to the conception of the hydro-geological model, interviews have been carried out with all important institutions of the Federal States Bavaria and Baden-Wuerttemberg concerning the availability of data and the possibility for gaining access to this data for use in the GLOWA project. While the state departments are very interested in the GLOWA project and willing to share their data, it has become apparent that the data situation is highly variable. This has proven to be especially true for the spatial density of available hydro-geological data. Therefore, geo-statistical methods such as Ordinary Kriging are currently utilised for areas for which little or no data is available. Figure 2 shows an example calculation of the aquifer base (boundary between the Quaternary and the Molasse) in the Danube Valley between Regensburg and Vilshofen using seismic reflection profiles with the help of a linear variogram. Even when data is available, it is mostly in the form of bore hole logs. Therefore, the pertinent information must be extracted, digitised and geo-referenced. Since these questions are of particular importance for the implementation of DANUBIA know-how in emerging and developing countries, students from these countries are actively involved in data preparation. Moreover, specific courses on data generation based on other parameters and on the use of GIS for further processing data have been offered to these students. During the remainder of the first project phase, the data acquisition will be continued with a special emphasis on the improvement of existing geo-statistical methods and the development of new ones.

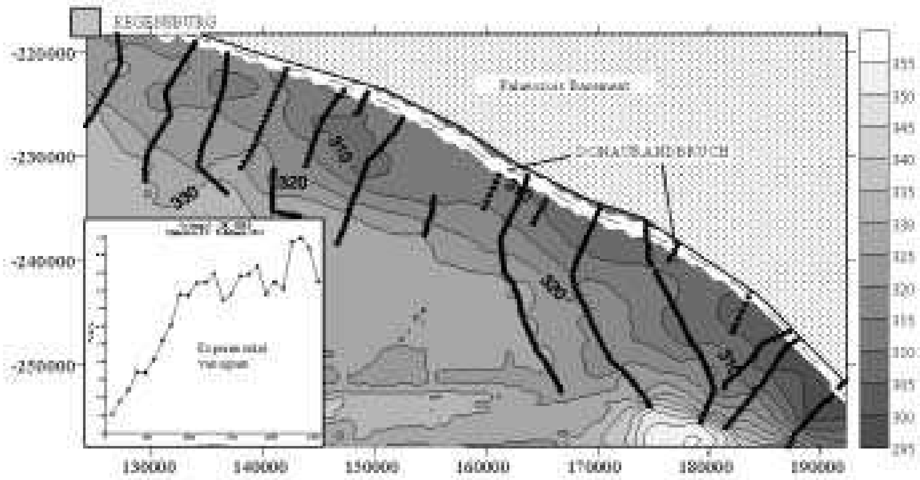

Fig. 2: Statistical approximation of the aquifer basis using Ordinary Kriging and seismic profiles (points) in the Danube Valley between Regensburg and Vilshofen near an important fault (Donaurandbruch). The small figure shows the appropriate experimental variogram.

While procuring data with the necessary spatial resolution, a second challenge must be addressed, namely the up-scaling of local, heterogeneous structures, such as line and point data sources, to fit the square kilometre grid. Prime examples for this problem are the river valleys crossing the catchment from the bordering Alps with courses aligned from South to North or

Southwest to Northeast. While these alluvial river valleys have small cross sections, they are at the same time significant aquifers due to their deposit's coarse grain size and the valley's steep gradients. Particularly when such structures run diagonally to the grid, their discretisation presents a great challenge. Rojanschi (3) pursued these and other similar questions extensively, and tested various methods for modelling the differences in hydraulic conductivity between a highly permeable Quaternary aquifer (Aitrachtal on the border between Bavaria and Baden-Wuerttemberg) and the surrounding Molasse based on the proxel size (1km²). His research showed that in many cases the up-scaling methods currently in use yield unsatisfying results. Hence, the second major research emphasis of the research group "Groundwater" is in the development of new scaling procedures.
Aside from setting up the actual flow and transport model, a particular thrust has been (and will be) on the integration of the large-scale groundwater model into the overall structure of DANUBIA to enable a continuous exchange of input and output data. The following table shows in an exemplary manner the transfer parameters between the group "Groundwater" and the groups "Landsurface" and "Rivernetwork".

Input data	**Provided by group**
RiverLevel	***RiverNetwork***
Nitrogen in surface water ***Nriver***	***RiverNetwork***
GroundwaterRecharge	***Landsurface***
Nitrogen in percolating water ***NLeaching***	***Landsurface***
GroundwaterWithdrawal	***WaterSupplyActor***

Output data	**Required by group**
GroundwaterLevel	***Landsurface***
Nitrogen in groundwater ***NGroundwater***	***Landsurface*** ***RiverNetwork*** ***WaterSupplyActor***
In-/exfiltration groundwater / surface water ***InExfiltration***	***RiverNetwork***

These transfer parameters were implemented in UML-diagrams (see "project overview"), which in turn were used to create a Java code which can be integrated in the overall structure of DANUBIA. In order to connect the FORTRAN programs to these Java interfaces, it is necessary to program a so-called wrapper. Concurrently an alternative solution to this problem is being tested. In an intermediate step, the structural inconsistencies between the two programs are evaded by reformatting FORTRAN tables in Java tables and vice versa. For the pilot project "DANUBIA 0.9", the data exchange between the groundwater model and the groups "Landsurface", "Rivernetwork" and "Actors" will be implemented using this approach. While this solution demands less programming effort, it may lead to performance problems. For this reason, the programming of the wrapper is still being pursued.

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THE ACTORS COMPONENT: A PREAMBLE TO THE BEHAVIORAL SCIENCES SUBPROJECTS

Author: A. Ernst

Abteilung Allgemeine Psychologie, Institut für Psychologie der Universität, 79085 Freiburg
ernst@psychologie.uni-freiburg.de;
http://www.psychologie.uni-freiburg.de/ressourcennutzung/glowa_danube/

Keywords: actor modeling – integrative methodology – social sciences simulation

Abstract:
The five behavioral sciences research groups in GLOWA-Danube ("Environmental psychology", "Agricultural economics", "Tourism", "Economics", "Water supply") face several interesting but also challenging scientific problems. There is a classical heterogeneity of the disciplinary approaches to the behavior of Man. Moreover, interdisciplinary approaches require spatially resolved models, and questions of spatial as well as temporal scaling that are yet to be answered.
To respond to these challenges in an integrated way, the "Actors" research group (made up from the above groups) uses the framework of actor modeling for their common approach. It aims at simulating the single actors' decisions (sometimes together with their goals, perception, knowledge, and learning) in a modular and theoretically founded way and is thus contrasted to summative modeling methods. Unifying concepts like bounded rational decision making can be brought to bear. Moreover, multi-actor modeling is a well-known approach in computer science.

Results:
The participating behavioral research groups have to exchange a multitude of data during runtime of DANUBIA, while the interfaces to the research groups external to the Actors component (i. e. "Groundwater", "Rivernetwork", and "Landsurface") turn out to be relatively lean. This led to the definition of the *Actors* object, which is – though a clear-cut functional unit – fully integrated in the DANUBIA model.
The "Actors" research group has been able to clarify their common approach to the scaling issues at stake. All groups will use the proxel approach of DANUBIA and thus be able to profit from geocomplexes using data from other research groups, e.g. remote sensing data about land use. This necessitates down- (e.g. "Economics") or upscaling (e.g. "Environmental psychology") from available data on the county vs. individual level. Methods like the "regional farm approach" (see research group "Agricultural economics") help achieving this task. The same is true for the time scales. The related research groups mostly use time scales from months up to one year within their models, but data exchanged with other DANUBIA objects use the overall DANUBIA time rate of one day.
While some of the research groups work on the refinement of existing models and their integration in the DANUBIA framework, others have – as a first step – implemented and integrated so-called "flat" actor models that use input-output functionality without relying on detailed data about the inner workings of decision making (e.g in the research group "Environmental Psychology"). "Deep" models including further assumptions will be implemented in several groups using a common architecture, as soon as the relevant data have been gathered. The "Economics" group will provide the necessary dynamic macro-economic and demographic framework data to the actors.

Project ID: 07 GWK 04 (research group "Environmental psychology")
project duration 01.10.2000 – 31.12.2003 report period: 01.01.2001 – 31.3.2002

MODELING OF TYPICAL DOMESTIC WATER CONSUMERS IN THE UPPER DANUBE BASIN

A. Ernst, R. Eisentraut, J. Kneer, M. Nethe

Abteilung Allgemeine Psychologie, Institut für Psychologie der Universität, 79085 Freiburg
ernst@psychologie.uni-freiburg.de;
http://www.psychologie.uni-freiburg.de/ressourcennutzung/glowa_danube/

Keywords: water use – actor modeling – acceptance of political measures

Abstract:
The aim of the environmental psychology component is to model in a spatially resolved way all households in terms of their water use decisions, their subjective perception of risks concerning water, and their acceptance of the political and water related status quo. From this, social science scenarios are to be created under conditions of global climate change to assess the potentials of conflict and risks of acceptance.
The psychological computer model DUNE (Domestic water Use and NEeds) is being constructed using both current theories about environmental behavior and a number of data that have been collected in advance. The model is fully integrated in the DANUBIA program. Each household type in every square kilometer proxel is represented with an individual model. In a first step, a "shallow" model describes the input-output relations calibrated to existing locally differentiated data. In a second step, a "deep" model will introduce theoretical assumptions about perception, decision making, and social interaction. This allows, apart from testing and providing theoretical explanations, to more easily integrate new types of actors and is thus refinable and extendable.

Results:
Theory building: The DUNE model has been fully conceptualized. It comprises one component to deal with objective variables (like household size), one with the economic aspects, and one with the psychological factors in decision making.
Data collection: Matching the variables from the theory, a questionnaire has been developed. It has been tested in two pilot studies. The data collection includes a representative telephone survey with 1000 households in the Danube basin prepared to start in June, a mail survey with 1000 questionnaires sent out to households around Ulm, starting in April. Extensive and detailed demographic data have been bought from the Bayerisches Landesamt für Statistik.
Implementation of the model: The "shallow" DUNE model has been implemented including the objective and the economic components and provides the spatially resolved domestic water use. It uses a local database (via the Internet) to serve demographic base data. Results are delivered to the central components of DANUBIA, also via Internet, and displayed visually.
Publications: One refereed journal publication, several refereed conference presentations, several invited talks.

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Project ID: 07 GWK 04 (Research group "Agro-Economy')
Project duration: 01.10.2001 – 31.12.2003 Report period: 01.10.2001 – 31.3.2002

SOCIO ECONOMIC ANALYSIS AND MODELLING OF AGRIGULTURAL WATER DEMAND AND LAND USE

S. Dabbert, S. Herrmann, T. Vogel, T. Winter

Institut für Landwirtschaftliche Betriebslehre (410A), Universität Hohenheim,
Schloss Osthof Süd, 70593 Stuttgart
dabbert@uni-hohenheim.de; http://www.uni-hohenheim.de

Keywords: optimisation model, agriculture, land use, water demand, GIS, PQP

Abstract:
The task of this project part is the socio-economic analysis and evaluation of the agricultural land use and of the water demand of agricultural production. The distribution of main agricultural land use types (grassland and arable) and the arable crop ratio determine groundwater recharge and other hydrological factors. The extend of irrigation influences the demand of water supply. Fertilisation level has an impact on water quality. A regional (district based) economic optimisation model will be used to represent the farmer's decisions. The objective function aims on the maximisation of agricultural income. A disaggregation tool will be developed to distribute the district based modelling results to each proxel. It's internal multi-criteria-decision-matrix is based on a rule framework derived from expert knowledge and information about site conditions as well as historical development.

Results:
The economic model could be characterised as a district-differentiated, comparative-static regional optimisation model. Using the method of positive mathematical programming (1), it represents the income and the production structure of agriculture. Currently, the definition of the different plant and animal production activities, represented in the model, takes place. Therefore, agricultural statistics and information about subsidies have been prepared and analysed. The general concept of the model algorithm has been tested and optimised. As a basis for the rule framework of the disaggregation-tool (2), interviews with experts from the governmental administration (land consolidation, agriculture, regional planning) have been performed. The first analysis of the results shows a good possibility of regionalising the statistical data and combining it with site condition information as well as formulating scenario assumptions. The final definition of the rules and their algorithmic formulation will be completed in the remaining phase. The connection with the central modelling system DANUBIA has been prepared by formulating the UML diagram. The object '*Farming*' has been integrated into the '*Actor*'s' object. The data exchange within the actors group takes place with '*Economy*' and '*WaterSupplyActor*'. Data about the production periods of the single crops and fertilisation height will be delivered to the object '*Landsurface*'. The preparation of the JAVA interface between the disaggregation-tool and the DANUBIA system is ongoing.

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2. DABBERT, S.; HERRMANN, S.; KAULE, G. and SOMMER, M., 1999, Landschaftsmodellierung für die Umweltplanung. Springer Verlag

Project ID: 07GWK04 (research group “Tourism”)
project duration: 01.10.2000 – 31.12.2003 report peroid: 01.01.2001 – 31.3.2002

RELATIONSHIP BETWEEN TOURISM AND THE RESOURCE WATER IN THE UPPER DANUBE BASIN

Jürgen Schmude, Astrid Piermeier

Lehrstuhl für Wirtschaftsgeographie, Universität Regensburg, Universitätsstraße 31, 93040 Regensburg
juergen.schmude@geographie.uni-regensburg.de; www.uni-regensburg.de/Fakultaeten

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Keywords: tourism – types of tourists – water consumption of tourists – tourism intensity

Abstract:
The natural environment represents a major and crucial factor of production within the tourism industry. The tourism industry regards water in the form of rivers and lakes as a part of the natural resources and thus it increases the desirability of tourist destinations. The aim of the research group “Tourism” is to model the effects of tourism on the basis of the significance of water as a factor of supply and demand in attractive tourist regions, as well as of the pertinence of supplies (i.e. infrastructure) and the actual recreation activities (i.e. degree of utilisation) which are linked to the availability of water/snow.
Simultaneously, the effects of tourism on the water balance of a region are taken into consideration on the basis of following aspects:

- *water consumption according to different kinds of tourism (types of tourists),*
- *possible changes in the behaviour of tourists which affect water consumption,*
- *environmental pollution due to the utilisation of land area covered with water or snow by tourists and conflict of utilisation of water (i.e. tourism industry vs. agriculture).*

Results:
The internal tourist model generating the TouristActor delivers both water consumption of the tourists according to different types of tourists and tourism intensity for every square kilometre proxel for the Actors model. In the future, modifications of the internal tourist model will be necessary to secure an optimal integration of the supply side of the tourism industry. After these modifications, the results will be delivered to DANUBIA.
Besides a very detailed research of written material, the first step was to establish a database containing socio-demographic, respectively tourist data on the basis of secondary (statistical)-data. The prerequisite for developing different scenarios was a cluster-analysis of specific primary (-statistical) data (interviews with hotel personnel and guests, interviews with experts, traffic census). By means of this specific primary (-statistical) data gained in several smaller segments within the total area under investigation, different "types of tourists" were classified in regard to their utilisation of water in the tourist destination. The analysis focused on how the socio-demographic characteristics and the existence of lakes determine the choices of the tourists for a certain region and the recreational activities conducted there.
This demand oriented method and the tight focus on socio-demographic data did not produce satisfying results. On one hand these various smaller segments under investigation proved to be too small, on the other hand the group of probands was too homogenous. Thus, the method to find out different types of tourists in regard to their utilisation of water has to be more supply oriented. This means that in future the emphasis will be put on the analysis of different types of offers of the tourism industry. Besides the modelling, the research group “Tourism” in cooperation with the research group “Economy” will conduct an analysis of the touristic labour market in the area under investigation.

Project ID: 07 GWK 04 (Research Group "Economy")
project duration: 01.10.2000 – 31.12.2003 report period: 1.1.2001 – 31.3.2002

A REGIONAL MODEL OF ECONOMIC DEVELOPMENT AND INDUSTRIAL WATER USE IN THE UPPER DANUBE BASIN

Prof. Dr. Rolf-Ulrich Sprenger, Dr. Johann Wackerbauer, Dipl.-Volkswirt Matthias Egerer, Dipl.-Volkswirt Erich Langmantel

Forschungsbereich Umwelt, Regionen, Verkehr, ifo Institut für Wirtschaftsforschung, Poschingerstraße 5, 81679 München
Sprenger@ifo.de; http://www.ifo.de

Key words: Regional-Economic Model, Natural Resource Economics, Water Use

Abstract:
The aim of the economic component is to model industrial activity and water use, population density and household income on a regionally disaggregated level and to derive rules for the setting of water prices. The economic model RIWU (Regional Industrial Water Use) is based on the assumption of a representative profit-maximising industrial firm which uses two local inputs, land and water. Industrial production and the local service sector dynamics determine the overall level of economic activity in the district, which in turn determines household income and population density. The model is integrated into the DANUBIA system: it provides other components with data concerning household income, population density and industrial water demand and uses data on water demand and supply from other components to set a water price. A disaggregation tool will be developed to distribute the district based model results to each proxel.

Results:
The model equations have been developed drawing on current results in the field of empirical regional-economic research. Data have been collected and the model equations have been estimated on the district level. In the outcome industrial activity depends positively on local exports and negatively on the prices of land and water use. The elasticity of industrial production with regard to the price of water use is markedly lower than with regard to land use. This reflects the fact that water is not scarce in the upper Danube basin. A first analysis of the simulation properties of the model shows satisfactory results. The object *Economy* has been integrated into the object *Actors*. The data exchange within the object *Actors* takes place with the "FarmingActor", the "HouseholdActor", the "TouristActor" and the 'WaterSupplyActor'. The connection with the central modelling system DANUBIA has been prepared by formulating the corresponding UML diagram. The next steps within GLOWA-Danube will be the development of a proxel-based spatially disaggregated economic model which allocates economic activities with respect to different types of land use to each square kilometer in the upper danube basin and the preparation of the JAVA interface between the disaggregation-tool and the DANUBIA system.

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Project ID: 07 GKW 04 (research group “Groundwater-Water Supplier”)
project duration: 01.10.2000 – 31.12.2003 report period: 01.01.2001 – 31.3.2002

GROUNDWATER MANAGEMENT AND WATER SUPPLY

C. Schmid, R. Barthel, D. Nickel, V. Rojanschi, J. Wolf, J. Braun

Lehrstuhl für Hydraulik und Grundwasser, Institut für Wasserbau, Universität Stuttgart, Pfaffenwaldring 61, 70550 Stuttgart;
christoph.schmid@iws.uni-stuttgart.de, http://www.iws.uni-stuttgart.de

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Keywords: Water Supply, Water Treatment, Decision Support System

Abstract:
The object WaterSupplyActor with its model Water Supplier is the main link between the Actor objects on one hand and the engineering and natural science models on the other. It obtains information about available water resources, aggregates the water demands of the different Actors (HouseholdActor, Economy, TouristActor, and Farming), develops a supply strategy, decides which water resources to use in order to meet the demands and informs the objects Groundwater and Rivernetwork accordingly.
Data on the potential water resources (quantity and quality) for each proxel is obtained from the Groundwater and Rivernetwork objects at each time step. This data is used as input for the model calculations performed in the model Water Supplier. The cost for water treatment for the respective raw water qualities and the costs for transportation and distribution are determined based on data obtained from statistical surveys and from water suppliers. The model aggregates the water demand of the Actors, which is exchanged within the DANUBIA network by means of Java interfaces (drinking water, raw water for industry and agriculture). It compares this demand data with the potentially available water resources. Making use of a decision support system (DSS), a supply strategy is developed. If the supply meets the demand, a DSS determines the economically and ecologically best possible source of water (groundwater only, surface water only, import of water, or conjunctive use) and conveys the necessary extraction rates to the supply models. Should the supply side not be able to meet the demand (due to changing climatic conditions or changing water quality), the model uses priority rules. Based on economical, political (e.g. agriculture vs. domestic use) or ecological (e.g. wetlands/lakes) parameters, the DSS decides on a supply strategy such that the maximum benefit for a majority of users is guaranteed.

Results:
In a first step the interfaces between the single objects were discussed and defined. As a result, the interfaces to the objects *HouseholdActor*, *Economy*, *TouristActor*, *Farming, Groundwater*, and *Rivernetwork* were set up. In the following step, the water supply structure of the Danube catchment was investigated in order to determine the initial model parameters. This has proven to be not only a challenging process but also a very time consuming one: the temporal and spatial scales of the available data are different than the data needed for the model. Therefore yearly extraction rates aggregated for administrative areas of varying sizes (e.g. villages, towns, counties) must be disaggregated to meet the model’s time scale and the proxel size of 1 km² while ensuring that the pertinent information is not lost.
The next steps will be to continue collecting data on the water supply structure and to develop methods for data aggregation. Another task will be to realise a first version of the Water Supplier as a Java model and to decide on rules for the DSS.

Project ID: 07 GWK 02
01.05.2000-30.04.2003

I M P E T U S West Africa

AN INTEGRATED APPROACH TO THE EFFICIENT MANAGEMENT OF SCARCE WATER RESOURCES IN WEST AFRICA

- CASE STUDIES FOR SELECTED RIVER CATCHMENTS IN DIFFERENT CLIMATIC ZONES -

P. Speth[1], B. Diekkrüger[2] and M. Christoph[1]

[1]Institut für Geophysik u. Meteorologie, Universität zu Köln, Kerpener Str. 13, D-50923 Köln
[2]Geographische Institute, Universität Bonn, Meckenheimer Allee 166, D-53115 Bonn
speth@meteo.uni-koeln.de; http://www.uni-koeln.de/globaler-wandel/impetus

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Key words: Hydrological cycle, global change, West Africa, river catchment, integrated approach

Abstract:

In Northwest and West Africa an increased occurrence of drought years since the early 1970s has brought a number of serious problems related to the fresh water supply. An integrated approach dealing with all aspects of the hydrological cycle is performed in the presented project. Investigations are carried out on the basis of two river catchments: the wadi Drâa in Morocco and the Ouémé river in Benin. During the first phase factors influencing the hydrological cycle have been identified and analysed. Different global change scenarios will be used in the second phase to predict the bandwidth of consequences regarding the fresh water supply on the local and regional scale. In the final two years the collected insights of all the disciplines will be coupled in order to assess management options and to install operational tools for the decision-making process (so called "Decision Support Systems").

Introduction:

Fresh water has already become critically scarce in many regions of the world. It is forecast that, for the first quarter of the 21st century, about one-quarter of the world population will suffer from severe water scarcity. For Africa some estimates suggest that already now the amount of fresh water available for each person is only about a quarter of that in 1950, and that fresh water supply could become problematic especially in West Africa, where about 30 years of drought have been observed. Although the climates of West Africa are still relatively poorly known and understood, it is recognised that Northwest and tropical West Africa have experienced the most pronounced inter-decadal variability of climate in the world during the 20th century. The possibility of human-induced climate change adds additional serious aspects to the challenging water-related problems already encountered in many parts of the world.

Motivation:

The available fresh water is controlled by the hydrological cycle. Climate, in particular the spatial and temporal distribution of precipitation and evaporation, plays a significant role in the hydrological cycle, and climate data are therefore of the utmost importance in the analysis of ground and surface water supply for domestic and industrial users, irrigation, hydropower generation and ecosystems. Dealing effectively with the hydrological cycle and its impacts demands not only a strong co-operation between different disciplines within the natural sciences (e.g. hydrology, meteorology, botany, agriculture, geology, remote sensing), but also consideration of socio-economic and medical issues; all disciplines involved have to interact in a complex and co-ordinated manner. Hence, in order to solve possible future problems with regard to fresh water supply, a clearly interdisciplinary approach is necessary. This is done in the present initiative for West Africa and it is the purpose of this project to offer concrete ways of translating into action scientific results through scientifically-based strategies. This approach will provide a reliable basis for political measures and international agreements. In the first three-year phase the focus is set on the identification and analysis of influencing factors regarding different aspects of the water budget. Based on this, in the second three-year phase methods will be developed to predict changes during the coming decades. In the final two years the collected insights of all the disciplines will be coupled in order to assess management options and to install operational tools for the decision-making process (so called "Decision Support Systems").

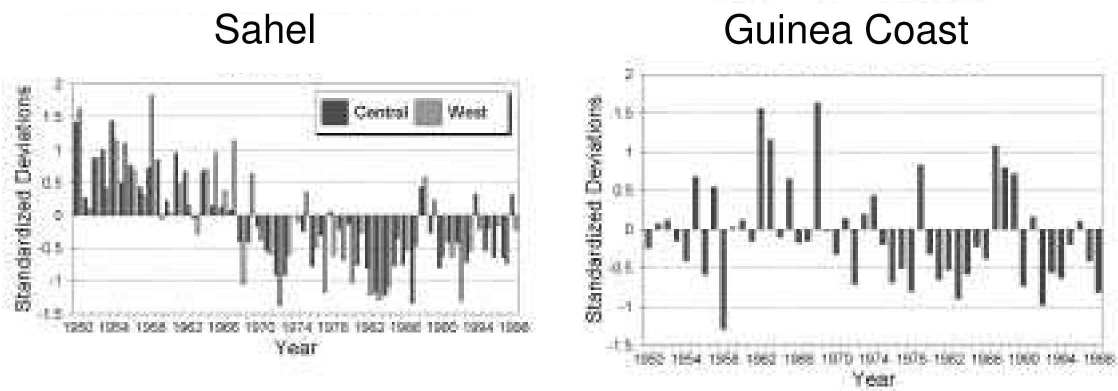

Fig. 1a Precipitation variability in West Africa for the period June - September 1950-1998.

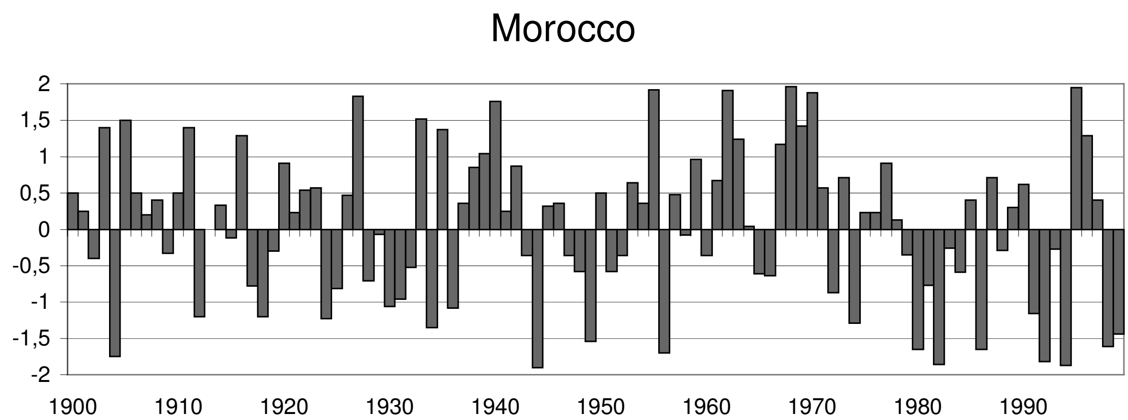

Fig. 1b Annual precipitation variability in Morocco throughout the 20th century.

Choice of Catchments:

West Africa was chosen because (i) it has experienced the most pronounced inter-decadal variability of climate in the world during the 20th century, (ii) relations to the climates of

Europe might exist via complex atmosphere-ocean interactions, and (iii) the regions north and south of the Sahara might be linked via atmospheric teleconnection processes with regard to precipitation anomalies; first results of subprojects A1 and B1 give strong hints for the existence of such a link by atmospheric moisture transports out of the West Sahel zone across the Sahara towards the Atlas mountains.

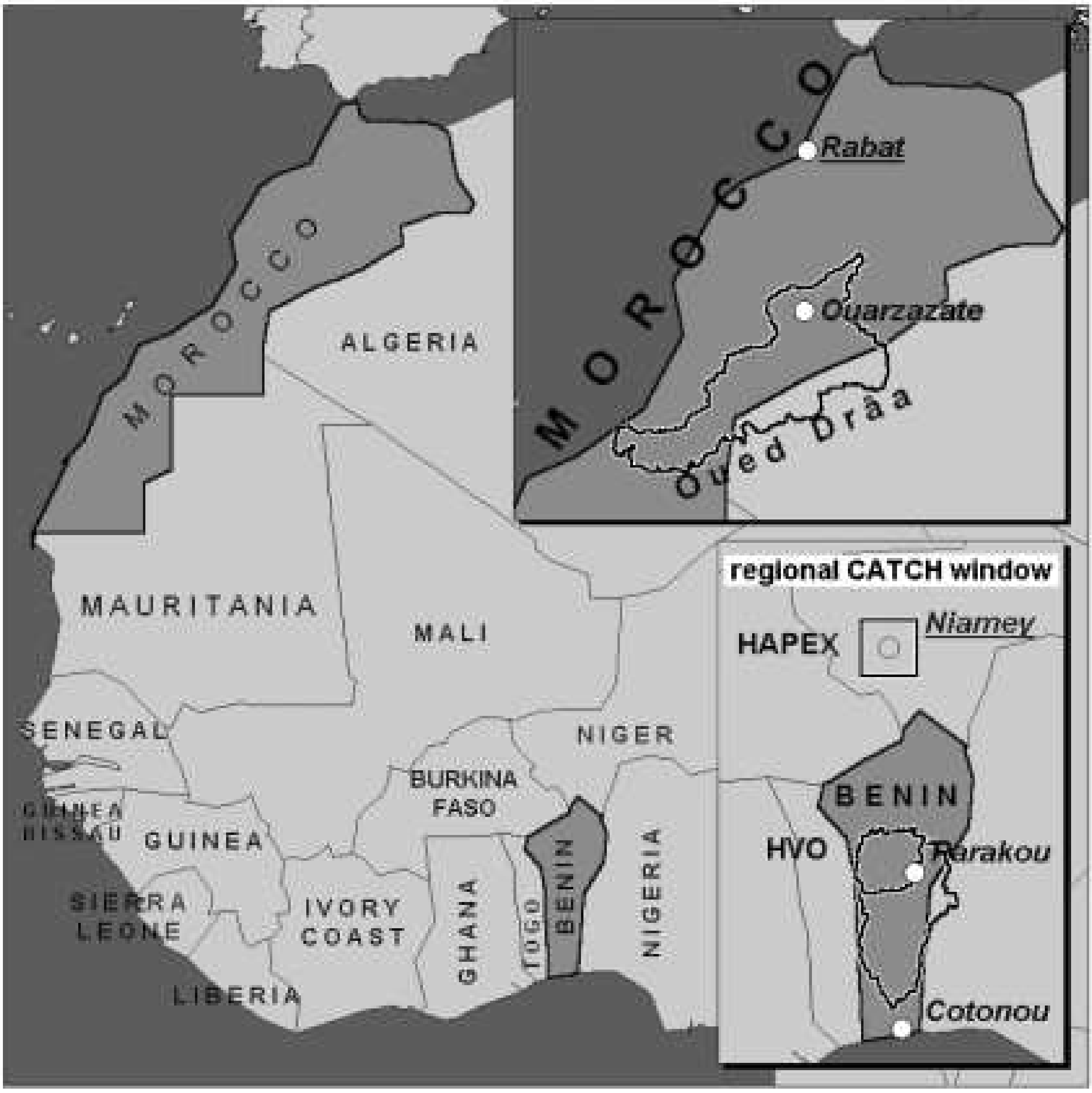

Fig. 2 The two catchments of consideration. The DRÂA catchment in Morocco and the OUÉMÉ catchment in Benin are boldly bordered. A sub-catchment of approx. 100x100 km west of Parakou (Haute Vallée de l'Ouémé: HVO) has been chosen as an area of focused investigations.

Since the 1970s both subtropical Northwest Africa and tropical West Africa have experienced a general rainfall decline which have probably been related (Fig. 1). For this reason it is of advantage to consider both areas north and south of the Sahara desert in a combined approach, realised by means of a transect between the Atlas mountains and the Gulf of Guinea (Fig. 2). This transect contains two reasonably sized river catchments (< 100.000 km^2) which are representative in the following sense: the Drâa catchment in the south east of Morocco is typical of a gradient from humid/sub-humid subtropical mountains to their arid foothills (see project B of this report); the Ouémé basin in Benin is typical of an alternating sub-humid climate

("Guineo-Soudanien") of the outer tropics embedded within a transect from the Sahelian to the Guinean Coast climate (see project A).

The feasibility of the presented initiative has been guaranteed by the good availability of data of both the natural and the human sciences and by politically stable conditions in the respective countries.

Past and Present Situation:

Since the early 1970s tropical West Africa has suffered from a prolonged drought that reached its first climax in the first half of the eighties. The average rainfall deficit over 1971-1990 was of the order of 180 mm/year compared with the interval 1951-1970. All climatic zones, from the semi-arid Sahel and the subhumid Sudanese zone down to the humid Gulf of Guinea, have been affected. The prolonged West African drought has already brought about a profound deterioration in the economic and social development of the West African countries. For example, river discharges in West Africa have decreased by about 40-60% in recent decades, causing shortages in river water available for domestic and agricultural purposes. For instance Fig. 3a shows the decrease in run-off of the Ouémé at Bétérou which reflects the integral for the southern part of the upper Ouémé catchment. This has led to extensive migrations in the past. During the rain-rich fifties, water power stations were built in the Guinea coast zone to supply a substantial amount of energy to Ivory coast, Ghana, Togo, Benin and Nigeria.

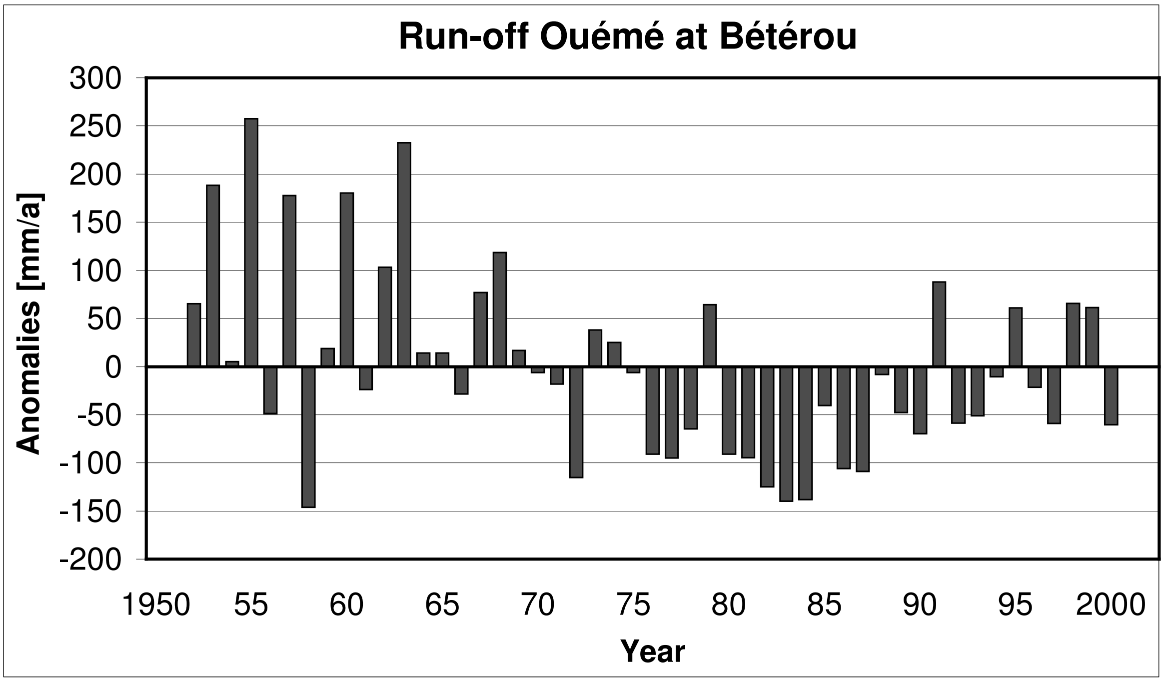

Fig. 3a Annual run-off anomalies of the Ouémé river at Bétérou for the period 1952 through 2000. Units are in mm/year, thereby taking into account the size of the upstream catchment area.

Moroccan precipitation is strongly related to the large-scale atmospheric circulation over the subtropical and extratropical North Atlantic and the Mediterranean Sea, with the bulk of precipitation occurring in winter (November - March). Since the late 1970s, Morocco has experienced a number of extremely dry winter seasons, the causes of which are not fully understood. Against this background, the development of sustainable water resource management is even more a necessity. The considered wadi Drâa possesses two main tributaries which drain the south-eastern and south-western parts of the Atlas and meet near the city of Ouarzazate. This is also the site of the Mansour Ed Dahbi dam that was built in 1968 and whose reservoir has a storage capacity of 530 million m^3. Approximately half of this amount is released in normal years. The main irrigation structures consist of five smaller dams downstream and a complex network of canals. Since the snow melt in spring contributes significantly to the annual discharge of the Drâa, diagnosing the spatial distribution of accumulated snow water equivalent in the elevated areas of the catchment is particularly desirable. An effective and sustainable management of water in the Drâa valley is essential to enable the competing users (water power generation, irrigation, domestic consumption) to have adequate supplies, and to prevent social tensions related to water resources. Fig. 3b shows the dramatic decrease in the filling of the reservoir in the last two years.

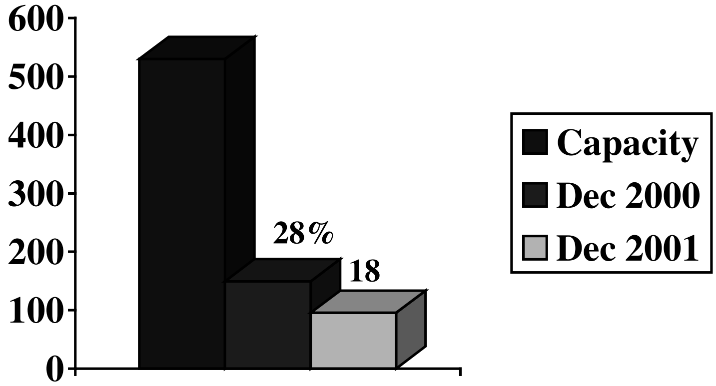

Fig. 3b Recent filling levels of the "Mansour Ed Dahbi" reservoir near Ouarzazate, Morocco.

Methodology:

The availability of fresh water is governed by the hydrological cycle. The different components and their interactions are considered in individual subprojects: the atmospheric variability in subprojects A1/B1, the continental hydrosphere in subprojects A2/B2 and the land surface processes in subprojects A3/B3. Human activities related to fresh water are investigated in subprojects A4/B4 and A5. In an integrated approach a sequence of existing models for the individual components have been adapted in the first project phase. These models will be coupled in subsequent phases with the ultimate goal to develop a decision support system. A measurement network of necessary parameters has been set up in data sparse areas. For the Ouémé catchment we concentrated on the upper Ouémé valley where the existing national and IRD hydrometeorological networks have been enforced with focus on a super test site 'Aguima' near Doguè (Fig. 4a). In the Drâa catchment 11 climate stations and 10 fenced vegetation plots were installed along a height gradient from the High Atlas to the pre-Saharan desert (Fig. 4b).

Co-operation:

Our research initiative is embedded within the local research structures of the countries where the research work is concentrated, i.e. predominantly Benin and Morocco. A large number of co-operation contracts with local institutions in these countries provide a sound basis. In addition to that efforts have been made to strengthen local public, traditional and private institutions and initiatives, and to enhance the local scientific knowledge, e.g. by. training courses and seminars. Exchange programs at the universities of Cologne and Bonn for foreign scientists and students support this process.

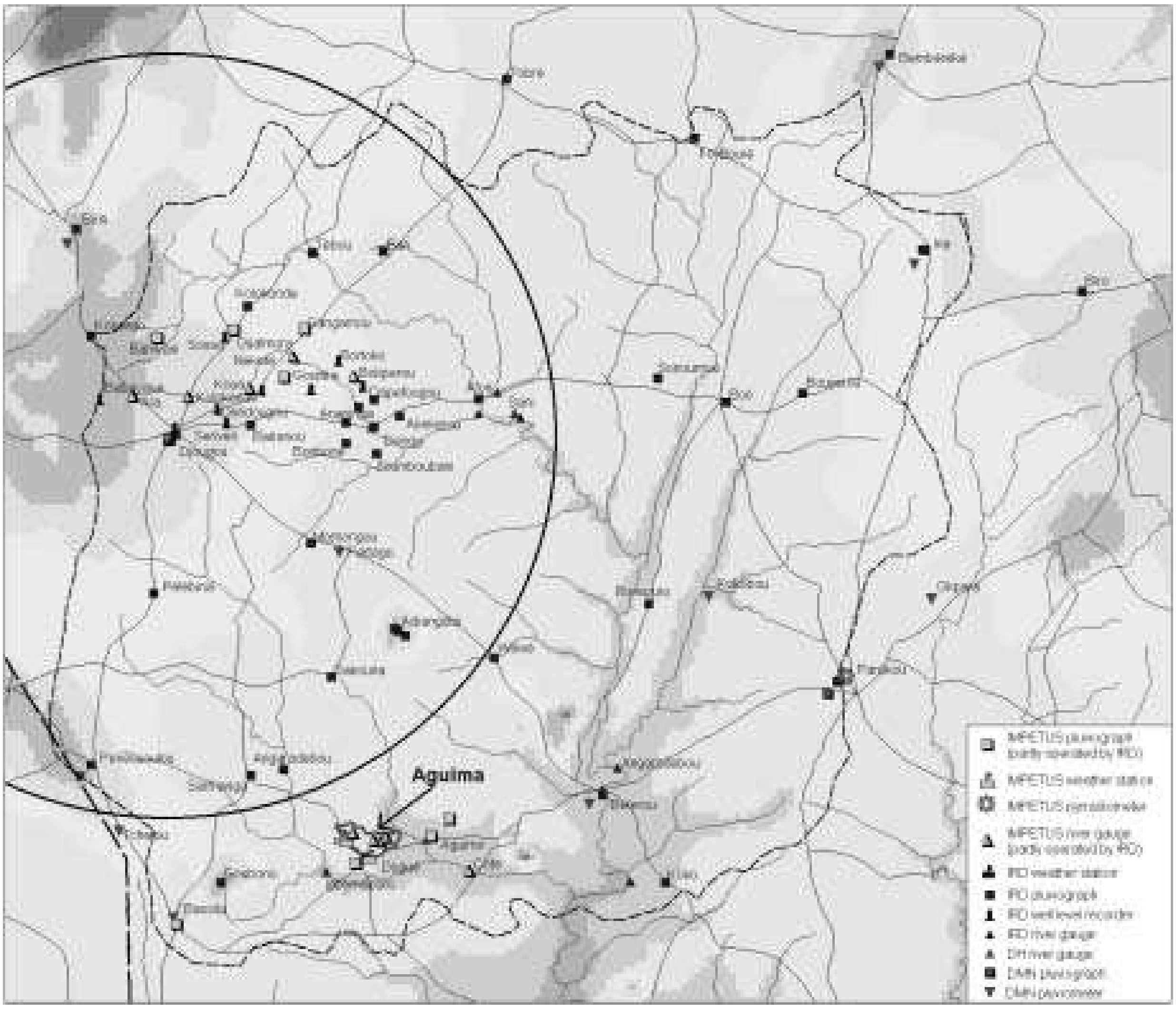

Fig. 4a Location of the IMPETUS measurement sites and additionally all other hydro-meteorological sites maintained by the following institutions:

- **D**irection **M**étéorologique **N**ationale (DMN, Benin)
- **D**irection de l´**H**ydraulique (DH, Benin)
- **I**nstitut de **R**echerche pour le **D**éveloppement (IRD, France)

The circle indicates the 60 km radius of the French X-band radar at Djougou (planned for 2003). During the period May - September 2002 IMPETUS will operate a radiosonde station at Parakou.

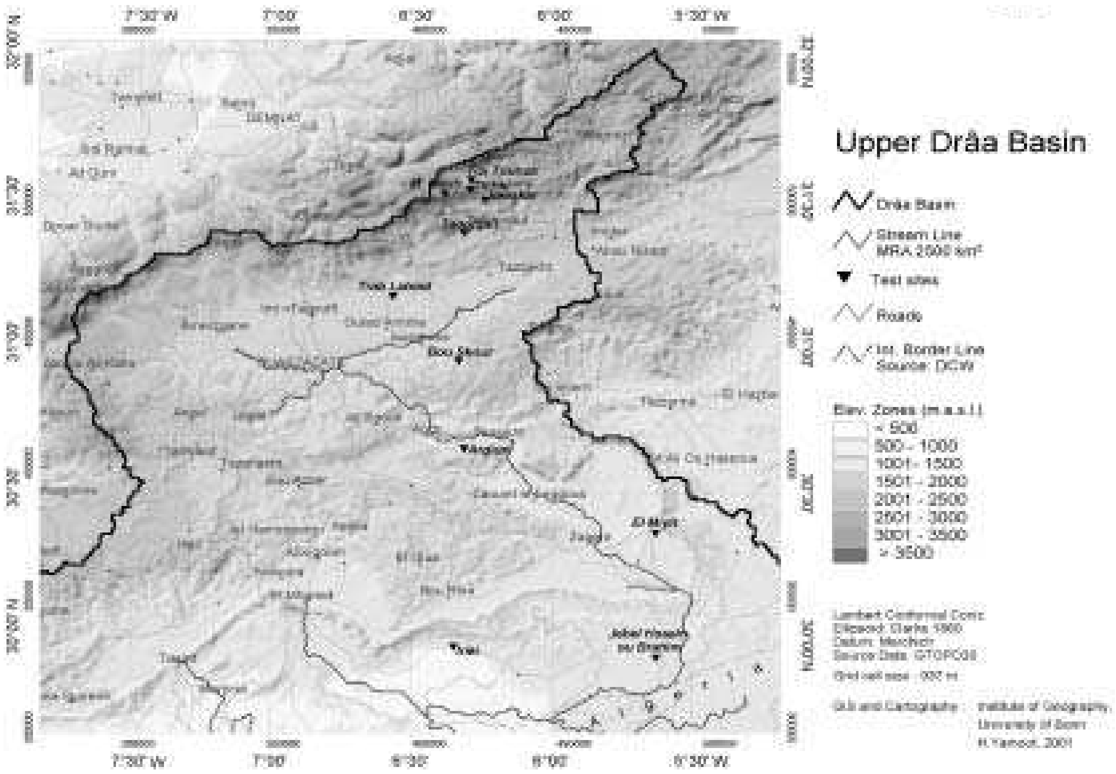

Fig. 4b Location of the IMPETUS measurement sites in the Drâa catchment in Morocco

Project ID: 07 GWK 02 (Subproject A1)
01.05.2000-30.04.2003

DIAGNOSTICS AND MODELLING OF THE SPATIAL RAINFALL VARIABILITY ON INTRASEASONAL TO DECADAL TIME SCALES

P. Speth[1], K. Born[2], A. H. Fink[1], R. Hagenbrock[2], A. Hense[2], M. Kerschgens[1], H. Paeth[2], J. Schulz[2], C. Simmer[2], M. Sogalla[1]

[1]Institut für Geophysik u. Meteorologie, Universität zu Köln, Kerpener Str. 13, D-50923 Köln
[2]Meteorologisches Institut, Universität Bonn, Auf dem Hügel 20, D-53121 Bonn
speth@meteo.uni-koeln.de; http://www.uni-koeln.de/globaler-wandel/impetus

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Key words: precipitation analyses, squall lines, remote sensing, model nesting, seasonal forecast, land surface changes, scale interaction

Abstract:

Analysis of precipitation trends reveals no return to normal or above-normal monsoon rains in all climatic zones of West Africa. During recent dry decades, shortfalls at the height of the rainy seasons were the major cause for the annual rainfall deficits in central-north Benin. In this region, African easterly waves (AEWs) were found to be a major trigger mechanism for squall lines (SLs) at the peak of the rainy seasons 1998 and 1999. A 0.25 x 0.25º monthly rainfall climatology is currently enhanced to daily resolution using METEOSAT Infrared (IR) imagery and a passive microwave rainfall algorithm has been successfully calibrated with the TRMM radar. As one result of studies with the general circulation model, ECHAM4, a combination of large-scale predictors were identified and used in a multiple cross-validated statistical model which demonstrates a remarkable forecast potential of almost 50% of seasonal rainfall variability. The use of the regional model LM for case studies of typical rainfall events on different scales enhanced the understanding of West African weather variability. Idealised and complex modelling studies with the FOOT3DK clearly disclose that it is the interplay of convection cells with both land surface processes and larger-scale atmospheric dynamics that eventually determines the rainfall anomaly pattern.

Results:

<u>Precipitation trends in Benin</u>

A standardised rainfall anomaly index for Benin as a whole, and the three overlapping subregions, South Benin (6-9ºN), Central Benin (7.5-10.5ºN) and North Benin (9-12ºN) has been developed from quality-checked historical daily rainfall data. From the rainfall indices, it is evident that a return to normal or above normal rainfall has not occurred in Benin. On the contrary, a slight negative trend emerges in recent years that is strongest at the Guinea Coast. This statement holds true for West Africa as a whole. At present, it remains unclear why the shift to a positive phase of the Atlantic decadal SST mode, that has occurred around 1995 and that favoured above-normal rainfall in West Africa in the 1950s and 1960s, has not led to a return to wetter years across West Africa. A vegetation feedback is just one, but a plausible, scenario for this behaviour.

<u>Synoptic wave disturbances (AEWs) and squall lines (SLs) in West Africa and Benin</u>

Using ECMWF analyses, TRMM and DMSP passive microwave sensors and METEOSAT three-hourly IR imagery, 81 African Easterly Waves (AEWs) and 344 Squall Lines (SLs) were manually identified and tracked over West Africa during May-October 1998 and 1999. SLs triggered by AEWs were defined as such SLs that were first detected on satellite images ahead of the AEW trough and, only in the Sahel (> 12.5ºN), in the region of the low-level moist northerlies. While 42% AEW-SLs were diagnosed for West Africa as a whole, this number is only 27% for Benin. The reasons are twofold. Firstly, 17 out of 83 SLs occurred already in May when the AEW activity is negligible. Secondly, AEWs grow in amplitude towards the Atlantic coast, but also in the course of the season. As consequence of the seasonal amplitude growth, the number of AEW-SLs in Benin rose to 48% in the July-September period. For the dry period, 1971-1990, it was found that shortfalls at the height of the rainy season in central-north Benin (August/September) were the major cause for the annual deficits. Thus, the causes for "dry" AEWs at the height of the rainy seasons are presently investigated.

Remote sensing and precipitation analysis

The principal aim of the use of meteorological satellite data within the IMPETUS project is the establishment of a satellite based rainfall monitoring system for northwest Africa with a special emphasis on the state of Benin. This requires the derivation of rainfall on instantaneous to climatological time scales using data from different types of radiometers (e.g. microwave and infrared) as well as rain gauge data. The results will be used to assess the quality of rainfall predictions provided by different meteorological models on different spatial and temporal scales. For the hydrological subprojects within IMPETUS, the satellite based rain information can be used as input to hydrological models in different river catchments. The climatological satellite products will also be delivered to the socio-economic parts of the project giving much better geographical rainfall distributions compared to maps derived from common station based measurements.

As a starting point the precipitation analysis for Benin consisted of analysed monthly aggregated precipitation fields. For this product the monthly precipitation estimates given by the CRU (0.5° × 0.5° spatial sampling) and the GPCC (1° × 1° spatial sampling), both based solely on rain gauge measurements, and the GPCP (2.5° × 2.5° spatial sampling), which is a merged satellite data product, were combined in a weighted sense. The weights were computed by transferring the error covariance given by the GPCP data set (which gives a parameterised estimate of the sampling error) to the other input grids. In the next step the measurements of the individual rain gauges within the Benin weather service and the CATCH networks were taken to enhance the resolution to 0.25° × 0.25°. During the data merging process the optimal set of parameterisations of other influencing factors, e.g. orography influences on monthly rainfall was found via a cross validation technique ("regression screening"). A temporal refinement towards daily values using METEOSAT IR imagery is currently under development.

The currently used quasi empirical baseline passive microwave algorithm (Bauer et al., 2002) is extended for the use with data from the TRMM satellite. The used technique makes a first order approach to remove seasonally varying surface contributions by maps of clear-sky temporal averages of brightness temperatures. The influence of more dynamic parameters like surface temperature and moisture is reduced by successive subtraction from the observations by means of principal component analysis. The resulting index of precipitation is then calibrated to a rain rate using collocated radar data from the same satellite. It was found that the functional dependence of the precipitation index and the radar-derived rain rate is very similar for different months and years. This is an encouraging result because the temporal and spatial stability of this calibration is of paramount importance for potentially transferring the calibration function to other passive microwave radiometers e.g. SSM/I and AMSR which is necessary to enhance the temporal sampling of passive microwave based rainfall estimates. The use of all available microwave radiometers will then establish the first version of the rainfall monitoring system at the end of the first project phase in early 2003.

Model results

A scale-comprehensive understanding of the mechanisms that cause rainfall variability in West Africa is the principal purpose of the meteorological model chain within IMPETUS. By co-ordinated model studies, the key interactions of the manifold processes that contribute to rainfall variability are identified and evaluated on all relevant temporal and spatial scales. This characterisation is the prerequisite to assess critical influences of possible global and regional changes on rainfall in the IMPETUS regions. In addition, the model chain is used to replenish meteorological information to fill observational gaps. The model hierarchy that covers the cascade from global to local scales consists of ECHAM4 (global climate model), REMO, (regional climate model), LM (regional meso-scale-α to -γ forecast model) and FOOT3DK (meso-scale-β to micro-scale-α research model). Each model can be forced by passive nesting into its larger-scale counterpart. Alternative forcing can be provided to REMO and LM by analysis data.

ECHAM4 is studied and compared with other climate models such as HADAM2 to investigate global and large-scale teleconnection patterns, the long-term variability from decadal to centennial time scales and the prospect of climate prediction. Special emphasis is put on the role of global sea surface temperature (SST) changes and increasing greenhouse gas (GHG) concentrations for West African rainfall fluctuations. The results represent a deciding factor for the forcing of smaller-scale atmospheric (A1) and hydrological (A2) models and might also enter in economic balancing and agricultural planning (A4). SST is a main factor in determining West African precipitation, especially south of the Sahara. The strongest link occurs to the tropical Atlantic and works via energy fluxes at the surface and large-scale monsoon dynamics (cf. Camberlin et al. 2001). Furthermore, there is a significant teleconnection to the tropical Pacific basin, involving the ENSO phenomenon. All predictors are combined in a multiple cross-validated statistical model and demonstrate a remarkable forecast potential of almost 50% of seasonal variability. In terms of rising GHG, there is a weak but statistically significant climate change signal in Sub-Saharan rainfall which is consistent with different coupled climate models and standing out against internal variability (cf. Hulme et al. 2001). This signal consists of steadily increasing annual rainfall into the future and contrasts the 20th century drought tendency.

Synoptic processes, which are not resolved in the global models, are picked up by the regional model REMO. This model is run at 0.5° resolution over the whole West African subcontinent and helps to understand the regional-scale synoptic mechanisms which induce rainfall variations over Benin and adjacent regions. REMO can be forced by either (re-)analyses or ECHAM4 data, and supplies the forcing data for smaller-scale atmospheric (A1) and hydrological (A2) models. Present simulations reveal a reasonable representation of the observed climate variability. REMO even reproduces some basic features of observed anomalous wet and dry rainy seasons in Benin.

The relation between mesoscale features of typical precipitation systems and synoptic-scale flow patterns is investigated with the non-hydrostatic mesoscale weather prediction model *Lokalmodell* (LM) of the German Weather Service (DWD). For this purpose, the model is forced by analysis data for the global weather prediction model GME acquired from the DWD. It operates on model areas with grid sizes ranging from 0.25° (synoptic scale) down to 1 km (mesoscale) and can be used for case studies of a few days up to a couple of weeks. One important question with respect to simulation quality is if the convection parameterization, which accounts for the largest part of the model rain in West Africa, performs well in the area of interest. Two important conclusions could be made: Firstly, deficiencies of the rain forecasts are mainly caused by insufficient initial data due to the sparse network of aerological stations in West Africa; secondly, even on smaller scales the use of a convection parameterization precipitation improves forecasts compared to using model scale physics only. The use of the LM for case studies of typical rainfall events on different scales enhanced the understanding of West African weather variability. Another important aspect is the current refinement of the land cover characterisation in co-operation with subproject A3.

The effect of interactions between the earth's surface and the atmosphere on fresh water availability in the Haute Vallée d'Ouémé (HVO) is the focus of investigations with the non-hydrostatic mesoscale model FOOT3DK. A combination of idealised ensemble simulations with a column version of the model and complex modelling of real precipitation events is employed to assess the sensitivity of precipitation to variations in the land surface. For the complex simulations, FOOT3DK is nested into LM forcing fields. Idealised studies exhibit a dominant influence of initial soil water content and an enhanced dependence of precipitation on vegetation when soil water availability is reduced. For wet soils, parameters that determine the intensity of near-surface turbulence are dominant. Complex modelling confirms that these relationships are useful to identify critical land use changes in realistic settings. However, the resulting regional structure of precipitation anomalies (Fig. A1-1) cannot exclusively be attributed to the pattern of hypothetical land use changes. It is the interplay of convection cells with both land surface processes and larger-scale atmospheric dynamics that eventually determines the rainfall anomaly pattern. Sensitivity analysis with FOOT3DK will be incorporated into a statistical–dynamical approach based on a classification of characteristic regimes that account for the rainfall in the HVO. This methodology will enable a regional assessment of rainfall reduction risks by future land use changes.

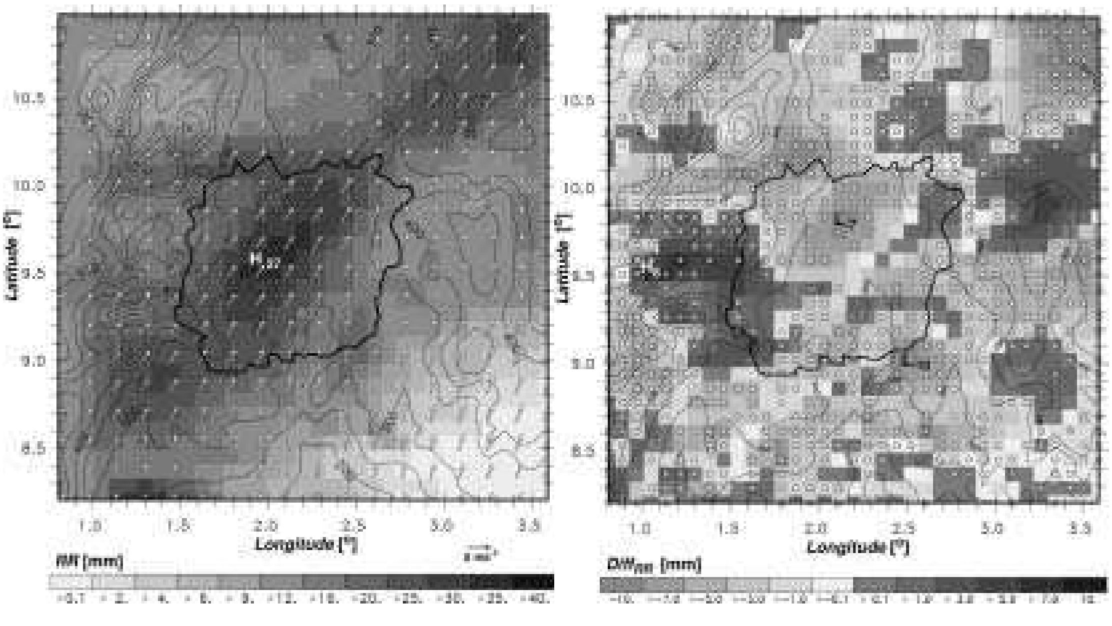

Fig. A1-1 Left: Accumulated precipitation and temporally averaged near-surface wind from July 28, 06 UTC to July 30, 06 UTC simulated by FOOT3DK for an undisturbed surface. Right: Differences in resulting for the same event if adverse properties for rainfall (reduction of vegetation, soil water, roughness; increase of albedo) are introduced at the grid points that are marked by dots.

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01.05.2000 – 30.04.2003

SOIL WATER DYNAMICS, SURFACE RUNOFF, GROUNDWATER RECHARGE AND SOIL DEGRADATION ON LOCAL TO REGIONAL SCALE

B. Diekkrüger[1], H. Bormann[1], T. Faß[2], S. Giertz[1], B. Junge[3], B. Reichert[2], A. Skowronek[3]

[1]Geographische Institute, Universität Bonn, Meckenheimer Allee 166, D-53115 Bonn
[2]Geologisches Institut, Universität Bonn, Nußallee 8, D-53115 Bonn
[3]Institut für Bodenkunde, Universität Bonn, Nußallee 13, D-53115 Bonn
b.diekkrueger@uni-bonn.de; http://www.uni-koeln.de/globaler-wandel/impetus/

Key words: catchment water fluxes, water balance, hydrological modelling, soil degradation, local to regional scale, scenario analysis, soil water dynamics.

Abstract:

The main task of the hydrological project A2 of IMPETUS is the description and quantification of the hydrological processes at different scales in Benin, West-Africa. It is the main goal to provide a hydrological modelling tool which enables us to perform a scenario analysis to assess the effects of environmental and anthropogenic change on the hydrological processes.
To attain this goal, a nested approach is used. At the local scale a representative, conjoint catchment has been selected by all working groups which acts as a super test site. Is has been arranged for instruments by all groups to comprehend the interrelations of properties and processes in the subhumid tropics. In particular the subproject focuses on the variability of soil water dynamics, groundwater recharge and soil degradation.
Based on the local scale measurements and the improved insight into the interrelations of properties and processes, hydrological model applications are performed at the local scale. Due to the fact that the meteorologists within IMPETUS already use the TOPLATS model (Famiglietti & Wood, 1994) as part of their atmospheric circulation models it has also been selected as hydrological model. At the local scale the model parameters can be measured directly or derived from mapping campaigns. Parameterisation schemes are developed which are needed for the regional scale hydrological modelling which have to be based on operationally available data (soil maps, land cover classifications) stored in a Hydro-GIS.

Results:

<u>Measurement concept</u>

The Aguima catchment (30km^2) has been selected as a super test site of IMPETUS. It is situated in the south of the upper Ouémé basin (ca. 14.000km^2). The catchment (ca. 250-320m above sea level) is part of a large plain and is dominated by savannah vegetation and agricultural used areas close to villages.
All measurements performed at the local scale are concentrated in this super test site (see fig. A2-1). During the first field campaigns the following permanent instruments has been installed:

- two climate stations (plus one additional of subproject A3),
- two dual soil water measurement stations under four different land use types (tensiometers and TDR-probes at different soil depths, suction cups),
- 32 TDR tubes covering the whole catchment area,
- four discharge measurement stations,
- 12 erosion measurement plots.

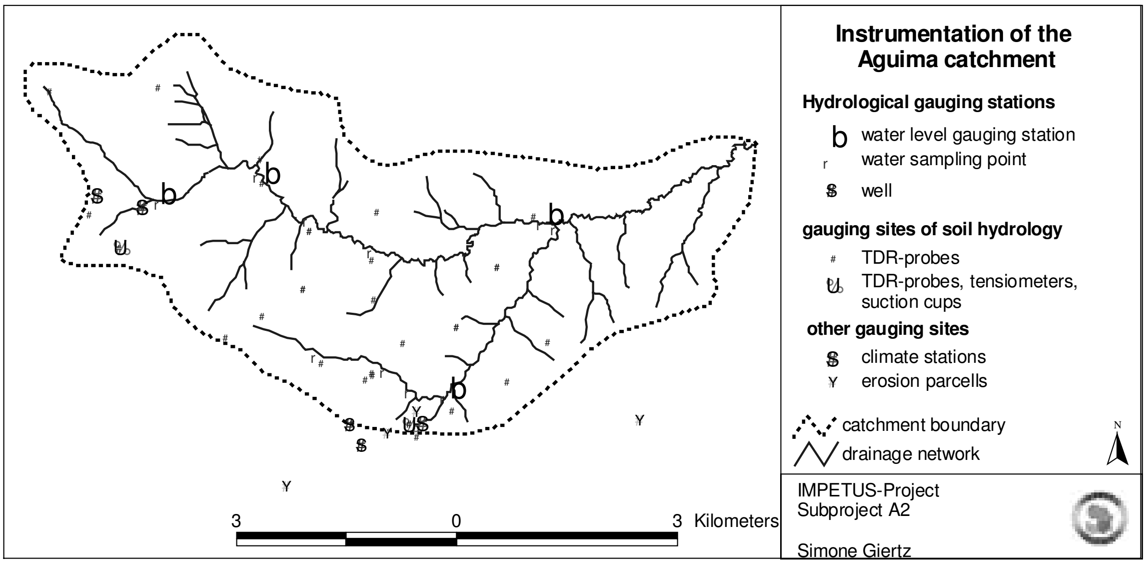

Fig A2-1: Hydro-climatological instrumentation of the super test site (Aguima catchment).

Additional to the permanent instruments a large number of campaigns have been carried out to determine soil-physical (e.g. Ks, Ku, pF, bulk density) and soil-chemical properties (e.g. nutrients, pH), to investigate the soil erosion process and to analyse the water chemistry of soil water, groundwater and surface water. One essential task to complete the knowledge on properties and processes at the local scale is the generation of the local soil map which is derived from 30 distributed profile holes and 410 drillings along transects.

Soil water dynamics

The data collection of the soil water measurement stations contributes to the analysis of the soil water dynamics related to the site properties such as soil and vegetation characteristics. The two soil water measurements stations are built up under different vegetation types, savannah and agricultural area. Both stations consist of eight tensiometers and eight TDR-probes in four depths, therefore two sub-sites are measured at a time. Additionally the spatially distributed TDR tubes enable an analysis of the spatial soil moisture pattern within the catchment which is mainly caused by soils, vegetation and topography.
The savannah site is divided into two sections with differently dense tree population (‘savanne boisée’ and ‘fôret clair’), at the agricultural site the soil water dynamics under maize and cotton is investigated. Maize and cotton are the predominant field crops in that area, ‘savanne boisée’ and ‘fôret clair’ are the predominant natural vegetation classes. Based on these measurements the estimation of the runoff production and groundwater recharge mechanisms depending on the site properties is feasible. First measurements show a quick reaction of storm events on soil moisture and runoff (Fig. A2-2).

Soil degradation / erosion

Actual soil erosion is examined at different scales during the whole rainy season. Erosion plots have been installed to measure erosion rates at the point scale, sediment traps and erosion pins to study the spatial pattern of soil erosion. As the highest erosion rates were expected on agricultural used areas, maize, peanut, cotton and yam fields were selected for installation. One extensively pastoral used savannah site was chosen as a reference.
The amount of eroded soil material strongly depends on the amount and the intensity of the rainfall events. Highest soil loss rates are observed during heavy rainfall events. Differences between the erosion rates of different cultures (Fig. A2-3) have mainly two reasons: the soil

loss of maize, cultivated in rows, is higher than soil loss of yam cultivated on mounds. In the end of the rainy season the relation changes due to the development of the leaf area index and the soil coverage by the canopy.

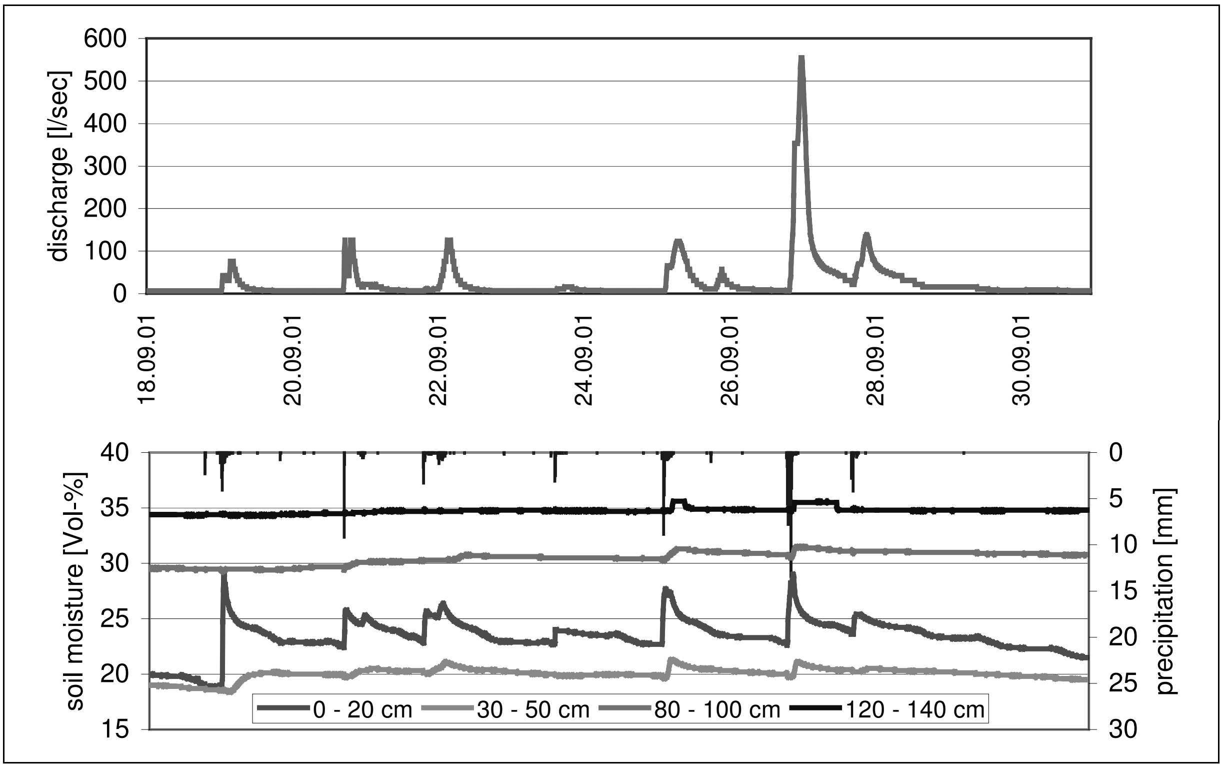

Fig. A2-2: Comparison of measured precipitation, discharge (Aguima) and soil moisture (savannah site).

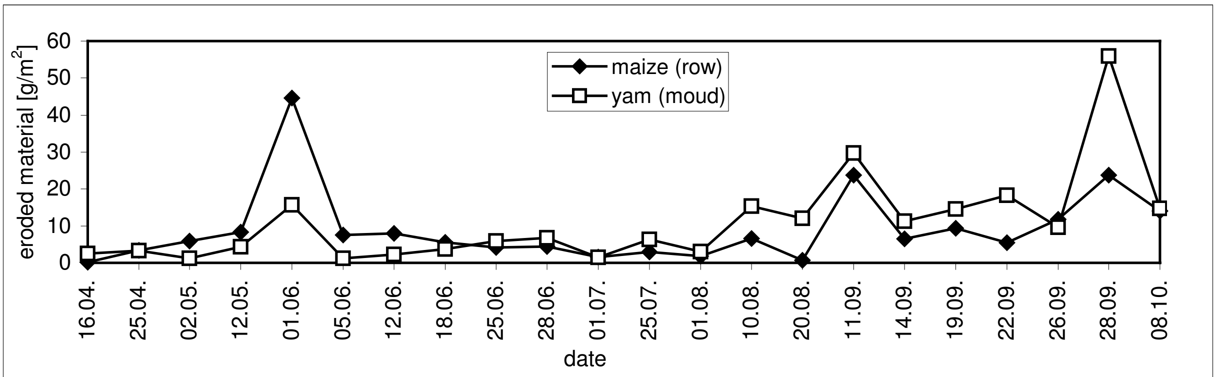

Fig. A2-3: Soil erosion of maize and yam, measured by sediment traps.

Hydrogeology and groundwater chemistry

The aquifer of the Aguima catchment is located within the migmatitic basement which consists of fractured rocks. The main fractures (NW-SE and SW-NE direction) represent the drain system of the groundwater which is captured in the two wells of the village Doguè.
The groundwater recharge process strongly depends on the composition of the lateritic weathering zone. Lateritic strengthened soil horizons may act as aquitards. The percolating water is then dammed up and forms interflow (depending on the slope conditions). If there are preferential flow paths in these aquitards, the water partly contributes to groundwater recharge. As the aquitardes do not cover the catchment as a whole, a direct percolation from the soil water zone to the groundwater is partly present. The origin and the age of water can be derived from the chemical composition of the water. Groundwater, soil water and surface water in the catchment differ significantly concerning their chemical composition (Fig. A2-4). Depending

on the storage time and aquifer mineralogy groundwater shows a higher mineral content. The soil water shows increased K and Ca concentrations, the surface water increased Fe, Na and Ca concentrations. To identify the flowpaths tracer tests will be carried out.

Local and regional water balances – hydrological modelling – Hydro-GIS: Based on the measurements of the first rainy season water balance terms at the local scale can be compared to regional water balance terms. At the savannah climate station near Doguè in 2001 an annual precipitation sum of about 800mm was measured. The runoff contribution of four small subcatchments of the Aguima (3-17 km^2) was between 23 and 136 mm/a, depending on soil and vegetation conditions. Thus as expected the catchment contributions to runoff at the local scale show a high variability but average to values comparable to regional scale values which can be seen by extrapolating the regression curve of the gauge station Térou-Wanou (fig. A2-5) to lower rainfall.

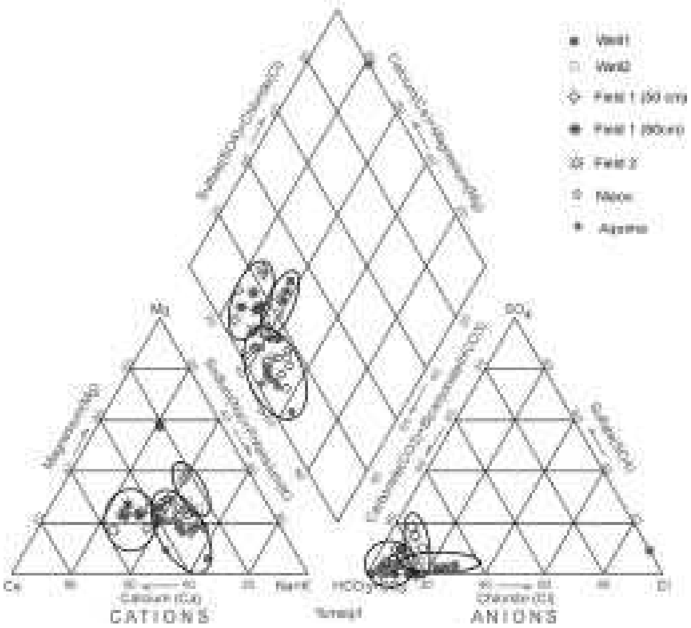

Fig. A2-4: PIPIER diagram of water samples - Aguima catchment and village Doguè.

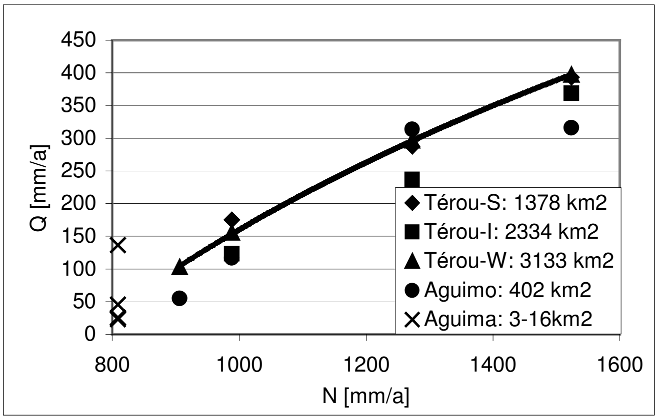

Fig.A2-5: Annual precipitation (station Doguè) versus discharge of four rivers in the upper Ouémé valley (1997-2000). Black line: logarithmic regression of the gauge Térou-Wanou.

For the hydrological modelling at the regional scale parameterisation rules developed at the local scale and a spatial data base (Hydro-GIS) are required. For the Térou basin which is a subbasin of the upper Ouémé valley following data were made digitally available:

- Digital soil map 1:200.000,
- Digital geological map 1:200.000,
- Digital elevation model (100m spatial resolution), derived from contour lines of the topographic map 1:200.000,
- USGS land use classification (1 km spatial resolution),

First regional simulation (parameters derived from Hydro-GIS and literature) have been performed for the Térou basin. The TOPLATS approach has been chosen as TOPLATS is already used as land surface scheme within the atmospheric model LM in IMPETUS. Since the parameterisation rules are still under development, the modelled discharge does not fit exactly the measured hydrographs.

References:

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FUNCTIONAL RELATIONSHIPS BETWEEN SPATIO-TEMPORAL VEGETATION DYNAMICS AND WATER CYCLE

G. Menz[1], W. Barthlott[3], J. Burkhardt[2], H. Goldbach[2], B. Orthmann[3], S. Porembski[3], M. Schulz[2], H.-P. Thamm[1]

[1]Geographische Institute, Universität Bonn, Meckenheimer Allee 166, D-53115 Bonn
[2]Agrikulturchemisches Institut, Universität Bonn, Karlrobert-Kreiten-Str. 13, D-53115 Bonn
[3]Botanisches Institut und Botanischer Garten, Universität Bonn, Meckenheimer Allee 170, D-53115 Bonn
menz@rsrg.uni-bonn.de; http://www.rsrg.uni-bonn.de

Key words: West-Africa, land use cover change, vegetation dynamics, remote sensing, water use efficiency, biomass, transpiration, regeneration potential

Abstract:

The IMPETUS subproject A3 employs a multidisciplinary approach to investigate the functional relationships between spatio-temporal vegetation dynamics and the hydrologic cycle in the Upper Ouémé catchment in central Benin. Vegetation within the catchment was assessed using remotely sensed data and processing. The hydrologic cycle and biomass production parameters of transpiration and radiation budget were measured in situ on several measurement stations and interpolated to wider areas. The vegetation dynamic was then analysed at time scales of a phenologic cycle as well in decades in detail on 39 field test plots and through remote sensing for the entire catchment. Dramatic land use and land cover changes were assessed within the study area for the last 20 years, and land cover change "hot spots" were identified. Based on this analysis, and in co-operation with other IMPETUS subprojects, it is possible to derive a land use change model which provides additional knowledge for important land use change factors, including socio-economic data. Interactions between the different vegetation types present within the study area and the hydrological cycle are fundamental to developing an appropriate hydrologic and development management system for the region. Additional investigations focused on the regeneration potential of forest areas following logging as well as on methods to increase agricultural water use efficiency are other important components in such a management system. Within Sub Project A3, new techniques and methods for a scientific approach to a rapidly changing semi-humid tropical environment where designed. The subproject is well integrated in the IMPETUS project, as well as with other international research groups and programs. These include the NASA's Land Use and Cover Change (LUCC), the International Geosphere Biosphere Programme (IGBP), IITA, GTZ, BIOTA and DANIDAT).

Goals:

The existing land use and land cover of an area is a key parameter within the hydrological cycle. In the IMPETUS project, the main goal of Subproject A3 is to investigate the functional relationship between the vegetation cover and water cycle using a process-orientated approach. Vegetation has high temporal and spatial dynamics in the study area, principally due to human impact and to the differing moisture regimes of the dry and wet seasons in the semi humid tropics. As an important step towards an integrated management system, it is necessary to assess these dynamics and understand their impacts on the hydrological cycle.

Research design and results:

In spite of organisation problems faced when working in a developing country, we have established a research program in the study area and have made significant progress to date.

Vegetation assessment

Development of vegetation test plots: The Upper Ouémé region is a part of the transition zone between the Northern Guinea Zone and the Southern Sudanian Zone. The natural vegetation in the area is characterised by tree- and scrub-savanna, with a high grass understory. As a part of this study, botanists have established 39 test sites, 30 m x 30 m in size, in the catchment area to asses the flora and to record relevant vegetation parameters, including basal area, height, leaf area index, biomass and many others. Large-scale vegetation dynamics are regularly monitored in these test sites. In order to assess of the impact of logging on the area's micro climate and the regeneration of forest, 72 transects, 5 m x 15 m in size, where established and each was equipped with a micro data logger. Local participants were recruited and trained in order to monitor each plot throughout the year. All information acquired from the test sites is assembled in a spatially related database, allowing ready access to the data by other members of the group.

Assessment of the actual land use / land cover with remote sensing: The Remote Sensing Research Group has the task of assessing the land use and land cover for the Ouémé catchment. This was done by classifying 30 m x 30 m LANDSAT ETM 7 satellite images. Employing optical sensors in a semi humid area is complicated by the presence of the dust and moisture typically present in the atmosphere. These conditions required intensive pre-processing of the LANDSAT image data. Advanced radiometric correction of the images was performed using the program STEAMER and meteorological reanalyses data as input. Additionally, the program ATCOR was used. A land cover classification system was developed in collaboration with the botanists and the meteorologists to meet the requirements of both groups. A sound basis for the classification system was established through an intensive field campaign to collect *in situ* vegetation data. In co-operation with GEOSYSTEMS, Inc. new tools for linking remote sensing images with GPS measurements were successfully developed and tested (THAMM & SCHMIDT, 2001). This effort lead to significant time savings and increased efficiency in field data gathering. As a final component of the field campaign, a comprehensive field database including digital photographs of more than 600 training areas was also compiled. The classification of remote sensing imagery to assess vegetation in the semi-humid tropics is a demanding task, principally due to the high inter-seasonal variability of the vegetation. Conventional classification methods based on spectral properties have their limitations in capturing this response variability. To solve this problem, a new knowledge based classification method utilising a multitemporal image set was developed and employed successfully (SCHÖTTKER & THAMM, 2001). This approach resulted in a 15 % increase in accuracy for classification of vegetation types which are subject to brush fire. Only very coarse resolution digital elevation models are available for the Ouémé catchment area of investigation. Data from the recently orbited ASTER satellite were used in combination with highly precise differential GPS measurements (DGPS) to produce a 30 m x 30 m resolution digital elevation model for the test area which we refer to as the "super test site". This study also had the goal of calculating leaf area indexes for the different vegetation types present within the study area. To complete this task, a number of *in situ* measurements were made and compared with similar values derived from satellite images.

Assessment of the relevant physiognomic and meteorological properties of the vegetation: The agriculture group determined transpiration rates, biomass and water use efficiency for the different vegetation units. This effort included working closely with local farmers in the test site. 150 individual fields were selected and cultivated with different crops (sorghum, cotton, maize, yams, peanuts). The biomass production and nutrient fluxes in relation to the water demand were determined for each field. Additional transpiration measurements were acquired through the use of a new instrument developed by Burkhardt, Inc. (Burkhardt et al., 1999; Burkhardt and Gerchau, 1994). These transpiration rate data were compared with transpiration rates derived from different methods including sap flow measurements and approaches using meteorological measurements. Two micrometeorological stations where installed in the study area to record the complete energy balance.

Vegetation dynamics

Assessment of the vegetation dynamics: Vegetation has different temporal dynamics: the inner-annual vegetation dynamic within the phenological cycle and the long-term vegetation dynamic caused by human or environmental factors such as long term climatic change.

Assessment of the inner-annual vegetation dynamic: The four LANDSAT ETM images which were acquired for this study show clearly the different stages of development within the vegetation phenological cycle and were used to conduct an investigation of the inner-annual vegetation dynamic in the study are. Fire within the study area is of great significance to the inner-annual vegetation dynamic: more than 40 % of the area in the Upper Ouémé catchment is subject to burning. That is an also an important factor concerning the overall carbon budget within the study area. The timing of the bush fires is also significant in the land use management concept for the area. Typically, fires are started by farmers at the end of the dry season, thus plant and soil nutrients will be washed out with the first rain. Early fires are not likely to go out of control and provide more time for the nutrients to penetrate the soil. We feel that information available from the new MODIS satellite will allow us to detect fires within the study area with even more precision. NOAA Advanced Very High Resolution Radiometer (AVHRR) images were also analysed in addition to the LANDSAT ETM scenes. When compared with the ETM data (with their relatively fine spatial resolution), AVHRR imagery has a much more coarse spatial resolution (1000 m x 1000 m) but a much finer temporal resolution with daily image acquisition. Vegetation information derived from the AVHRR data is valuable as input for meteorological models or to verify the model results. Information derived from these remote sensing inputs over the entire Ouémé catchment is then compared with field test plot information generated by the botanists along with the micrometeorological spot measurements performed by agronomists, following interpolation of the field test plot data and point source meteorological data to greater spatial units.

Assessment of the long-term vegetation dynamics: The long-term vegetation dynamic within the study area was derived through analysis of historical LANDSAT TM imagery acquired during the 1980's and comparison of these data with existing vegetation cover. Three different change detection methods were employed: Principal Component method (PC), change vector analysis and post classification method. The land use and land cover of some portions of the Upper Ouémé were subject to significant changes between the 1980 and 2000. In the "Forêt de l'Ouémé" area, approximately 15 % of the area changed from forest to field and settlements. The main settlement lines are along the roads; examples include the road between Ndali and Djougoum and the road between Woubéro and Bassila, both of which were enlarged during the early 1990's. Settlement in these areas is extremely dynamic and land use and cover change is quite rapid; our research indicates than more than 10 new settlements were present just in the one year period between 1999 and 2000. In addition to the settlement with areas of natural vegetation cover, commercial logging is a significant environmental problem in the area of investigation. Four timber species (Khaya senegalensis, Afzelia africana, Isoberlina doka, Pterocarpus erinaceus) are subject to large- scale logging. Botanists have recorded more than 350 cut down trees (through count of remaining tree trunks) in an area of only 5 km x 2 km within a year. Urban settlements have also expanded between the 1980's and 2000. Both major cities within the test site, Parakou and Djougou, as well as smaller towns like Bassila, have increased their area by nearly 50 %. Information regarding

land use and land cover in the area change were combined with the socio-economic data collected from the IMPETUS subproject A4. These data include precise demographic data for every village and new settlement along Woubéro-Bassila road. This data set is very useful for the developing of a land use and land cover change model for the region and for estimating future urban land area demands for in the area.
Establishing an integrated land use management system will also allow the preservation of critical areas within the region by identifying such land cover units as forest sanctuaries. Analysis of remote sensing data shows clearly that human development and urban expansion stop precisely at the boundaries of the sanctuaries. This phenomenon is observed at the northern boarder of the "Forêt de l'Ouémé". In addition, areas where the borders of the sanctuaries are being violated can be readily identified using satellite imagery, and sanctions may then be put into effect. The 1980 and 2000 land use classifications can also be used as inputs for climate and hydrologic models to more accurately estimate the impact that changes in land use and land cover may have on the hydrological cycle.

Activities towards a management concept

In addition to the important research activities to estimate the influence of land use change on the hydrological cycle described above, additional activities are ongoing which focus on developing and implementing a scientific system of regional land use management.
Increasing crop water use efficiency: Colonisation is closely related to the efficiency of agriculture in the region. If yields per hectare can be increased, less new area has to be colonised. Agronomists are currently investigating the impacts of different fertilizer types on the yield on their 150 test fields in the study area. Of special interest is the use of organic fertilizers which are meant to improve the water holding capacity of soils.
Estimating the regeneration potential of forests: Botanists are investigating the mechanism of forest regeneration following logging. By analysing changes in micro climate in logged forest clearings and by performing seeding probes, estimates may be made regarding which types of trees regenerate in which size of forest clearing. This aids in accurately estimate the size of forest patches which must be preserved for regeneration of selected tree species.
Implementation of a land use and land cover change model: A land use and land cover change model can be developed which describes the process of land use and land cover change and may be used to predict future changes in the region. This model is based upon the land use and land cover changes detected with remote sensing along with the socio-economic data generated by IMPETUS Sub Project A4. This model will be of particular use in estimating land use and land cover changes which may be induced by development projects such a building a new road or expanding and existing road. In addition, significant land use and land cover change "hot spots" can be defined within the region.

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SOCIO-DEMOGRAPHIC DEVELOPMENT AND MIGRATION AGAINST THE BACKGROUND OF RESOURCE SCARCITY

W. Schug[1], C. Behle[1], M. Doevenspeck[2], W. Henrichsmeyer[1], M. Janssens[3], R. M'barek[1], V. Mulindabigwi[3], M. Schopp[1], U. Singer[2]

[1]Institut für Agrarpolitik, Marktforschung und Wirtschaftssoziologie der Universität Bonn, Nußallee 21, D-53115 Bonn
[2]Geographische Institute, Universität Bonn, Meckenheimer Allee 166, D-53115 Bonn
[3]Institut für Obstbau und Gemüsebau, Universität Bonn, Auf dem Hügel 6, D-53121 Bonn
schug@agp.uni-bonn.de; http://www.uni-koeln.de/globaler-wandel/impetus/

Key words: Water supply, population growth, development strategy, resource availability, migration, settlement; land-use-systems, modelling, supply and demand functions

Abstract:

The main objective of various research activities in this subproject is to analyse the interdependencies between resource availability and socio-economic respectively demographic development in selected places in Benin.
Because of completely lacking or incomplete time series of secondary data the investigation is partly based on empirical social research. Most of the work packages still remain in the phase of data collection and of preliminary evaluation. The status of preparing the necessary data-set and developing conceptional framework is still different because of manifold problems including recruiting scientific staff or restrictions in working conditions.
Due to the actual findings, it is obvious that Benin at all does not belong to those countries with poor water supply. It is most of all a problem of an urban-rural-dualism in water availability related to different water-access and use. In those places with water-scarcity or water insecurity this is the problem of highest priority for the population.
As far as development strategies and related institutions are dealing with the improvement of resource availability it seems to be that the approaches do not meet the need of the population.
In the field of migration it is quite clear that the settlement takes place in an institutional vacuum and without governmental support. The consequences are transformations of socio-economic structures on local level and changes in land use patterns, caused by migration as well as by significant political problems in managing property rights.
Finally collecting of data on natural indicators related to land use systems show very different regional conditions. According to the efficiency of water application and capacity of soils in CO_2-storage the expansion of agricultural production is different.

Results:

The investigation on water supply, which started in 2000 is mostly based on an interdisciplinary analysis of selected private households at different places. In view of the fact that Benin shows a supply of renewed sweet water of 4.800 cubic metres per capita and per year it is not a water poor country exceeding significantly the limit of 1.001 to 1.666 cubic metres for water scarcity. Problems in water availability mostly are obvious on regional and local level. In this context the differences in water consumption between urban and rural areas show a clear picture. During the rainy season the average water use per capita and per day is 18,9 liters com-

pared to urban inhabitants with 28,7 litres. The range of consumption per capita is extended in urban households up to 69,9 litres, because of access to different sources in water supply. In villages, the distribution of water consumption is nearly equal caused by identical living conditions. For example, there is no possibility to buy water in dry seasons, if the own well dries up.
Water scarcity is a problem of very high importance if households mention their environmental risks. Related to their personal situation in daily life, the aspect of water supply only ranks on fourth position beside lack of money, disease and poverty. In spite of temporary water-insecurity this is no reason for migration, which obviously is due to private property of house and cultivated area. Beyond this, it is a seasonal phenomenon for which solutions should be available. In general the majority of the population included in the investigation points to the fact that there are no indications for water conflicts.

Less encouraging are the results of the effects of development strategies including the efficiency of related institutions. Based on a cross-section- and an in-depth-analysis the research activities on one hand were aimed at the identification of organisations supporting agricultural development and introducing micro-credit-schemes as well as being engaged in the process of decentralisation. On the other hand the analysis intended to describe and to evaluate different methods concerning for example the analysis of problems, targeted intervention to certain groups of population or to selected regions. On this background, the concatenation of actions and their effects is a very important aspect, which will result in development-orientated profiles of villages. The result of investigating 41 national and international organisations indicate that they hardly affect the agricultural sector in spite of the fact that this sector mostly influences natural resources.
A more differentiated judgement presents the following findings:

- The establishment of micro-credit-schemes did not include poor people, which are not organised, but are in need of external support.
- The co-operation with people migrating from outside did not work, because they only stayed for a limited time, which made it impossible to integrate these people into society.
- Women have been a preferred group as beneficiaries of micro-credit-schemes because they have a higher saving quota and thus, the ability to pay the credit back.

In the same way the results of the evaluation of projects in 5 villages and of 2 infrastructure programmes show that its effects on food production respectively on income generating were limited. Most of all migrating people could not profit from these activities as shown above.

Concerning the aspect of migration in a narrower sense and the dynamics of settlement it is important to know the new social background created by migrants, their forms of political organisation and integration as well as their impact on the transformation of the traditional systems. The results present a sobering picture insofar as the process of decision making within separated groups of migrants is informal and characterised by anarchic structures. On the background of a keen competition on the control of new institutions on village level there are winners and losers of social change leading to significant shifts of the traditional structure of power.
Beyond this the investigation shows that – caused by migration – land-use-patterns change and that new forms of cultivation are introduced. These results will be important for the next step of research, when the interdisciplinary modelling will take into account changes in surface covering and the process of deforestation.
Analysing the problem of property rights, the conclusion is obvious that migrating farmers are confronted with local owners. The traditional legislation on property does not give any legal protection to the newcomers, which again affects the utilisation of natural resources. So, for

example, the prohibition of investment in tree planting will prevent reforestation of cleared areas.

Summarising the development, the results indicate that conflicts on property rights will increase – a challenge which is to be managed by reforms of political structures on local level.

Concerning the influence of land use systems on organic matter dynamics and on water use efficiency, the following approaches and results are interesting:

With the demographic pressure on the land, the farmers who still have enough land to clear, maintain or increase their level of production through the extension of the agricultural area whereas those who do not it reduce the duration of the fallow. That involves a fall of the biomass production and consequently a low content of soil organic matter. According to the importance of water and the organic matter in the agricultural production, this study analyses the influence of the land use systems on the organic matter dynamic and the water use efficiency. After the quantitative data collections and analyse, the villages of Doguè and Sérou were selected respectively, as representing the villages which have still land to clear and those which do not have it. The land use in each village has been divided into four land use systems: forests, fallows, cashew plantations and other crops areas (cassava, yam, maize, sorghum, rice, beans, groundnut, cotton, ...). Observations and quantitative data gathering began in June 2001. Parameters include litter fall, organic matter, height of the crops/trees, leaf area, biomass production, soil water, soil CO_2 emission...etc and are taken within sixty four samples whose dimensions of each one are 30m*30m.
Concerning the organic matter dynamics and the carbon sequestration, the preliminary results show that the biomass production during the farming season (June –November) 2001 is higher in the samples of the crops area in Doguè (5.2T/ha) and Sérou (5.0T/ha) than it is in any other land use system. If one considers the biomass production of each land use system during all 12 months, it is probable that the food crops provide less litter. Whereas the majority of the food crops produce their biomass between June and November, the cashew plantations and the forests continue to provide litter especially in dry season. The forest of Sérou comes in 2^{nd} place with a litter production from 2.3T/ha. The Cashew plantations in Doguè and Sérou produced respectively 0,4 and 1,1T/ha litter. The forest of Sérou (with 6,2T/ha soil litter) as well as the cashew plantations in Doguè (3.5 T/ha) and Sérou (4.9T/ha) can be defined as CO_2 sink. Whereas in the other samples (forest of Doguè, fallows), bush fires and the burning of the harvest residues destroy all the litter and recycle the carbon in the form of gases (CO_2, CO.) in the air, the areas of cashew as well as the forest of Sérou are carefully protected against the fire. The CO_2 emission from the soil under different land use systems was higher in rain season and between 0.6 and 1.8 g/m^2-h.

The water use efficiency in the different land use systems in Sérou, is summarised in the table below.

Water use efficiency under different land use systems in Sérou:

Land use system	**Biomass production (Kg/m^3)**			**Calories production ($Kcal/m^3$)**	
Other crops area	0,551			357,0	
Cashew	0,131	Tubers	0,542	Tubers	301,2
Fallow	0,028	Leguminous	0,450	Leguminous	287,8
Forest	0,260	Cereals	0,661	Cereals	482,1

Supposing that 2000 Kcal are the daily needs of each person in Sérou, and that 75% (1500 Kcal) of calories come from the production of tubers, leguminous plants and of cereals, 4,2m^3

water are currently necessary to produce the 1500 Kcal (1533,6m^3 as annual water requirement per capita in Sérou).
A final approach is dealing with the analysis of long-term perspectives of economic, social and demographic development under alternative scenarios of resource availability and socio-economic framework conditions by calculations on simulation basis. The main methodical tool is the programming of a recursive-dynamic model of the agricultural sector.
The model is still in preparation and the necessary data adequate to the model are collected respectively, they will be provided by national and international organisations

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RISK AND INSECURITY WHEN RESOURCES ARE SCARCE: ETHNOLOGICAL AND MEDICAL PERSPECTIVES ON THE AVAILABILITY, QUALITY AND MANAGEMENT OF WATER

J. Rissland[1], R. Baginski[3], N. Bako-Arifari[2], M. Bollig[2], S. Denzel[1], K. Hadjer[2], T. Klein[2], B. Körner[1], H. Kulartz[1], H. Pfister[1], F. Sauter[3]

[1]Institut für Virologie, Universität zu Köln, Fürst-Pücklerstr. 56, D-50935 Köln
[2]Institut für Völkerkunde, Universität zu Köln, Albertus-Magnus-Platz, D-50923 Köln
[3]Institut für Medizinische Mikrobiologie und Hygiene, Universität zu Köln, Goldenfelsstr. 21, D-50937 Köln
juergen.rissland@medizin.uni-koeln.de; http://www.medizin.uni-koeln.de/institute/virologie

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Key words: Risk theories, indigenous medicine, waterborne diseases

Abstract:

The aim of the project is the assessment of risks caused by complex water problems in Benin. In this interdisciplinary approach anthropological and medical sciences (bacteriology and virology) are collaborating. Modern risk theories provide a basis for the holistic analysis. Main issues are the detection of communal "hazards" influencing the water system with respect to quantity and quality, the local perceptions of these dangers and the role of local risk minimising strategies. Due to the long term characteristics of anthropological studies and the establishment of required settings in the medical part (laboratory construction, method validation) only preliminary results have been obtained from 3 out of 5 work packages. Malaria, respiratory and gastrointestinal infections are the leading diseases on the single village level, highlighting hookworms as predominant parasites. Although no significant differences could be observed, more infections have been seen in well- than in surface-water dependant collectives. Daily water consumption was approximate 17 litre per inhabitant. So far over 60 water samples have been taken out of 900 mapped locations (well and surface waters). First line analysis showed approximately 1300 isolates of bacterial species, requiring further differentiation and epidemiological judging.

Background:

The availability and quality of drinking water is crucial for the inhabitants of the West African Sahel and Sudan zones. Through their direct influence on agricultural productivity and health both factors have an impact on settlement and mobility patterns. In addition they determine the local strategies of resource exploitation and the epidemiology of the whole region. As a consequence of the decreasing water resources, the growing population and the burden of endemic infectious diseases tropical countries like Benin face this situation in a more extreme sense. Conflicts begin to raise on a local level concerning the use and the distribution of limited resources, spreading eventually even to the developed part of the world. Therefore the conception and evaluation of risk minimising strategies is decisive from a local, regional and global point of view.

Objectives:

The subproject A5 of IMPETUS combines the disciplines of anthropology and medicine representing the idea that only a holistic analysis of water problems meets the requirements for efficient management strategies. The common basis for both sciences is provided by modern risk theories. Main issues are the detection of communal "hazards" influencing the water system with respect to quantity and quality, the local perceptions of these dangers and the role of local risk minimising strategies. Five work packages have been created to cover these problems:

The work package "Management of water and of water-dependant resources in local, social and political settings of the upper Ouémé region" deals with the interaction between economy, migration and conflicts on a regional scale. This investigation focuses on the documentation and comparative analysis of economically, culturally and historically differing concepts of water use.

In the work package "Water households economy in the upper Ouémé basin" social and economic strategies are analysed on a local (village) level. Surveys and interviews are used to evaluate the agricultural production as well as consumption patterns with special attention to social inequality and changing owner rights.

The work package “Water and health conditions: indigenous medicines in the Haute Vallée de l’ Ouémé" assembles different perceptions and practices related to water dependant sickness. Local disease and health concepts as well as preventive and curative measures are analysed by interviews and participating observations.

The work package "Water and infection: quality of drinking water and epidemiology of water associated infectious diseases in the Ouémé-Region" includes the detection, characterisation and quantification of water-transmitted bacteria with respect to WHO advice.

In the work package "Proof of viral indicators in various sources of drinking water in the upper Ouémé basin" the risk of virally contaminated water is investigated. By testing virological indicators (Entero-viruses, Norwalk-Viruses and Hepatitis E Virus) the effect of these agents on local epidemiology is assessed.

Results:

Due to the special character of the anthropological studies with long-term field campaigns and the establishment of required settings (laboratory construction, method validation) actually only preliminary results and observations exist. As a consequence the inherent medically orientated work packages are presented exclusively in the following.

<u>Water and health conditions: Indigenous medicines in the “Haute Vallée de l’ Ouémé”</u>

Research has been carried out for more than twelve months in Dendougou, a small village of about 500 inhabitants in the north-east of Djougou. Basic indicators of the local situation were gained by a micro-census. People living in Dendougou belong to 12 different ethnic groups, predominately Yom (36,5 %), Cocoma (18,7%) and Fulbe (17 %). All other ethnic groups are below 10 %. 52 % of the married population is living monogamous versus 48 % polygamous respectively. Only 21 % of the population older than 6 years had a formalized education (7 % went to primary school, 2 % to a koranic school, 12% learned to read and write in a campaign fighting illiteracy). 60 % of the villagers are Moslems, 4 % are Christians and 1 % rely on Fetishism, but 35 % practice no religion at all. Interestingly most of the Moslem, Christian and Atheist families possess a family fetish (60% of all families). There are three different resources of water in Dendougou: Well water, rainwater and water of rivers or waterholes. 16 % of all families rely entirely on surface water resources during the dry and rainy season.

Based on this descriptive data, three long-time studies have been effectuated in the second half of 2001:

From Autumn 2001 to January 2002 a longitudinal health survey in eight selected families has been undertaken, thus covering one rainy as well as one dry season. Families with access to well water were included in addition to families which entirely rely on water from the river or

water holes. First analysis showed malaria, fatigue and fever associated illnesses as leading diseases, followed by respiratory and gastrointestinal infections. Interestingly no significant difference between the well- and the surface-dependant groups could be detected, suggesting equal water qualities. Never the less observations showed slightly more infections among people using well water resources.
A second longitudinal health survey focused on the examination of blood and stool samples of the indigenous population, which were analysed twice monthly at a laboratory in Djougou. The tests were concentrated on malaria and intestinal parasites, showing that 55 up to 73 % of the population had actual manifestations or at least former contact. Under 47 infected people 32 cases (72 %) were due to *Necator americanus* (the sub-Saharan variant of *Ancylostoma dudenale)*, which causes intestinal infection. These hookworms both infect man by penetrating the intact skin, usually of the feet. The absence of latrines and the lack of shoes were suggested as main factors favouring this route of transmission. Again there were little more infections in the well related group.
The third study concentrated on the consumption patterns of water in the local setting of Dendougou. It was effectuated in close co-operation with the subprojects A4-1 and A5-2, thus allowing a comparison of different rural and urban settings (precisely the villages Bougou, Dendougou, Pélébina, Sérou and the town of Djougou). The daily water consumption in Dendougou was approximate 17 (range 15 - 20) litres per inhabitant.
More complex analysis of the collected data has to be done to identify the main influencing factors, including the influences of indigenous medical specialists on health concepts and disease models in different ethnic and gender groups.

Waterborne pathogens in the upper Ouémé-region

Due to a restricted infrastructure especially in the countryside of Benin a stationary laboratory and a mobile unit for the collection and transport of water samples had to be established on the ground of the *Service Regional de l`Hydraulique* in Parakou before starting the analysis. In addition more than 900 easy accessible watering places (wells and surface water) in the area between Parakou, Djougou and Bassila have been mapped and transferred into a special database. These locations will serve as primary objects for taking the samples. Water-associated bacteria will be detected by cultivation on special media and differentiated by serological, biochemical or genetical methods, followed by investigation of resistance patterns. The analysis of virological indicators (Entero-viruses, Norwalk-virus, Hepatitis E virus) combines the pre-analytical concentration of water samples in a transportable system with the detection of viruses and viral RNA by cell culture or polymerase chain reaction, respectively. For technical reasons some parts of this work has to be performed in the German laboratories of the project leaders, requiring airway transportation.
Following the successful custom agreement between Germany and Benin in August 2001, the establishment of the required settings as well as the validation of the laboratory methods have been finished by the end of the year 2001. Meanwhile (15.03.2002) more than 60 water samples have been taken from different locations in the catchment and analysis is still ongoing. First line analysis showed approximately 1300 isolates of bacterial species requiring further differentiation. The relevance of these results will be judged dependant on the local epidemiological situation. Data for this investigation will be collected by special questionnaires during the ethno-medical collaboration in the subproject A5. Furthermore results of the climate observation studies (subproject A1), hydrological and geological examinations (subproject A2), exploitation of the soil and dynamics of vegetation (subproject A3), as well as data on the regional development of the population (subproject A4) will be integrated in the epidemiological analysis.

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SPATIAL AND TEMPORAL VARIABILITY OF PRECIPITATION

P. Speth[1], K. Born[2], M. Christoph[1], A. Hense[2], H. Hübener[1], M. Kerschgens[1], P. Knippertz[1], H. Paeth[2], J. Schulz[2], C. Simmer[2], M. Sogalla[1]

[1]Institut für Geophysik u. Meteorologie, Universität zu Köln, Kerpener Str. 13, D-50923 Köln
[2]Meteorologisches Institut, Universität Bonn, Auf dem Hügel 20, D-53121 Bonn
speth@meteo.uni-koeln.de; http://www.uni-koeln.de/globaler-wandel/impetus

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Key words: Precipitation diagnosis, tropical-extratropical interactions, remote sensing, meteorological modelling, scale-interactions, land surface-atmosphere interactions

Abstract:

The principal goals of the meteorological subproject B1 consist of the determination of the atmospheric branch of the water budget for the Drâa catchment and the assessment of the mechanisms that control regional precipitation/evaporation variability. These objectives are pursued by a twofold strategy based upon diagnostic and model studies. Both large-scale and regional-scale influences on precipitation and evaporation are analysed for time-scales from decades to single events in order to obtain a picture of the physical mechanisms behind Moroccan precipitation generation and its spatial and temporal variability. It is shown that precipitation south of the Atlas is to an important part determined by interactions between extratropical and tropical synoptic systems. The latter are significantly influenced by Atlantic sea surface temperatures and the North Atlantic Oscillation teleconnection pattern. High resolution modelling of individual precipitation events gives further insight into the underlying mechanisms and provides an interface to the estimation of snow ablation in the High Atlas as an important freshwater source for the Drâa. Plant transpiration and soil moisture in the Drâa valley itself are decisive factors for freshwater loss due to evaporation and significantly influence regional near-ground atmospheric flow, which can even lead to modification of the isolated convective showers in the region. The results of the scale-comprehensive process analysis obtained in B1 will enter the assessment of potential effects on freshwater availability in the Drâa catchment by global and regional changes.

Results:

<u>Diagnosis of mechanisms for precipitation variability in Morocco</u>

Due to its geographical location between the North Atlantic storm track and the West African monsoon region, Morocco receives precipitation in connection with both extratropical and tropical regimes, which have been separately investigated. Extratropically induced precipitation, that is dominant in winter along the Atlantic coast, has been investigated by statistical analysis on a climatological basis. Mechanisms of tropically influenced precipitation have been studied with the help of case studies of rainy episodes in late summer/early autumn, when particularly the semi-arid to arid zones south of the Atlas mountains receive significant contributions to their annual rainfall amounts.

Winter time (DJF) precipitation in the north-western parts of Morocco shows a clear dependence on the position of the North Atlantic storm track. In months with large precipitation a southward to south-westward shift of the eastern end of the North Atlantic storm track is found, which is accompanied by an enlarged local cyclone and upper-level trough activity

north of Morocco and in the western Mediterranean. Baroclinicity is enhanced south of 45°N over the Atlantic in these situations. Corresponding westerly circulation weather types lead to an enhanced low-level moisture transport from the Atlantic into Morocco. Since sea level pressure is below normal west of the Iberian Peninsula in high precipitation months, a large negative correlation to the North Atlantic Oscillation (NAO) is found (for a schematic summary see Fig. B1-1a). Winter precipitation in north-east Morocco, north-west Algeria and south of the Atlas, however, appears to be stronger related to more localised cyclone activity. A strong low-level moisture transport from the Atlantic along the southern flank of the Atlas Mountains associated with cyclones west or north-west of Morocco can be identified as a decisive factor for precipitation south of the Atlas in winter. In contrast, north-east Morocco and north-west Algeria is dominated by the influence of cyclones in the western Mediterranean that are associated with enhanced baroclinicity over northern Africa and the Mediterranean and that lead to north-westerly moisture transports into this area.
The considered late summer/early autumn cases all reveal tropical-extratropical interactions (for a schematic picture see Fig. B1-1b). By trajectory analysis, tropical convection over Africa and the Atlantic – partly triggered by African Easterly Waves - could be identified as moisture sources for the rainy episodes. The moisture is transported northward, east of the axis of an upper-level subtropical trough, that extends anomalously deep into the tropics. The exact position and propagation direction of the trough, however, varies between the considered cases. In contrast to the extratropically induced precipitation regime, most moisture is transported at mid-levels, mostly above the dry Saharan planetary boundary layer. The moisture converges between 700 and 400 hPa over north-western Africa underneath a strong upper-level divergence centre, that is probably related to the advection of positive vorticity ahead of the trough. The resulting dynamically forced ascent, in connection with orographic lifting and surface heating, triggers convective rainfalls which occur preferably close to and downwind of the mountain chain. Precipitation intensities are mostly small to moderate, but some events of more than 20 mm in 12 hours were observed, particularly if the tropical air merges with an extratropical front over north-west Africa.

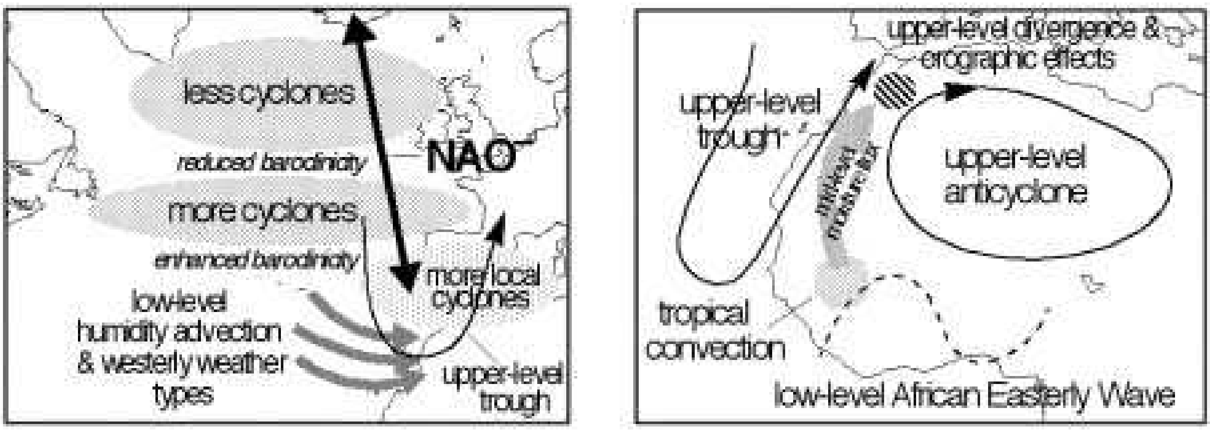

Fig. B1-1: Schematic overview of the principal mechanisms for precipitation generation in northwestern Africa: (a) extratropically induced rainfall (predominantly during the winter half-year) and (b) tropically induced rainfall (predominantly during late summer/early autumn). For details see explications in the text.

Improvement of observational data by remote sensing

As in subproject A1, the lack of ground based rainfall observations, which are especially sparse south of the Atlas mountains, is sought to be overcome by the establishment of a satellite based rainfall monitoring system. The methodology is the same as in A1. In support of identifying remote water vapour source regions for precipitation events in the Atlas region, satellite data are also used to derive the evaporation over the sea surface in the tropical Atlantic and the Mediterranean. The use of satellite data concentrates upon the derivation of the basic state variables wind speed, sea surface temperature, and near surface atmospheric specific humidity. Moreover, recently available TRMM satellite data allows for the first time estimates of evaporation from instrumentation on the same platform. Data from the Visible Infrared Scanner and the TRMM Microwave Imager have been used to derive monthly averages of the above mentioned basic state variables and evaporation. These new estimates were compared to older estimates from the HOAPS data set (Grassl et al., 2000). In spite of several differences, the HOAPS data set is fairly usable and biases can now be assessed using the new estimates from TRMM. At this stage of the project, a time series of 12 years (1987 – 1998) consisting of pentad and monthly averages on a $0.5° \times 0.5°$ spatial grid is available.

Results of model studies

Investigations with the global climate model ECHAM4 as part of the meteorological model chain within IMPETUS (cf. A1 for an overview) confirm the observational results depicted above with respect to influences of the NAO on Moroccan rainfall. In terms of sea surface temperature (SST), the North Atlantic subtropical and extratropical tripole in SST anomalies, which is itself linked to the NAO, plays a distinct role in Moroccan precipitation rather than the tropical teleconnections. Rising greenhouse gas (GHG) concentrations seem to cause decreasing rainfall amount over Northwest Africa which is likely to be connected with a positive trend in the NAO circulation mode (Paeth et al., 1999). However, the signal is weak and not consistent with all considered climate model versions.

As observations are especially sparse over Northwest Africa, the regional model REMO (cf. A1 for details) is run in a long term climate mode to supply a decadal rainfall climatology from 1991 onward to be used by all subprojects. Meanwhile, the rainfall climatology covers almost three years and is in excellent agreement with the CRU observation data (New et al., 2000). Future investigations will include a detailed analysis of the relevant synoptic processes and supply post-processed data sets of important atmospheric variables for all subprojects. Furthermore, it is intended to force REMO with ECHAM4 scenario simulations to obtain a valuable database for predicting vegetation changes (cf. B3) and socio-economic implications (cf. B4).

An improved understanding of mesoscale features of precipitation events in the vicinity of the Atlas Mountains is obtained by process studies with the the *Lokalmodell* (LM) (cf. A1 for details). The synoptic scale forcing of cyclonic, frontal and mesoscale convective rainfall events was investigated in detail. The model simulates the interaction between tropical dynamics and midlatitude synoptic phenomena consistently with the observational results depicted above and gives further insight into the underlying mechanisms: For example, moisture convergence connected with extratropical fronts crossing the Atlas ridge, which leads to penetrating convection, usually causes rain only in the region north of the Atlas Mountains, unless there is a conveying of moist, tropical air from the south-east (see Fig. B1-2). At present, the capability of forecasting thunderstorms is enhanced by using remote sensing data (from radar network and TRMM satellite) to improve initial fields of cloud water.

In order to supply snow ablation modelling in the High Atlas mountains (cf. B2) with meteorological forcing by observational or LM data, a computationally inexpensive coupler has been designed, which interpolates atmospheric data to small scale hydrological grids and calculates surface energy and moisture fluxes (Born, 2001). The meteorological coupler is tested with IMPETUS climate station network data (cf. B2-2). As a first result, the influence of evaporation on snow ablation has been found to be on the order of magnitude of the snowmelt, which is much stronger than in mid-latitude alpine regions.

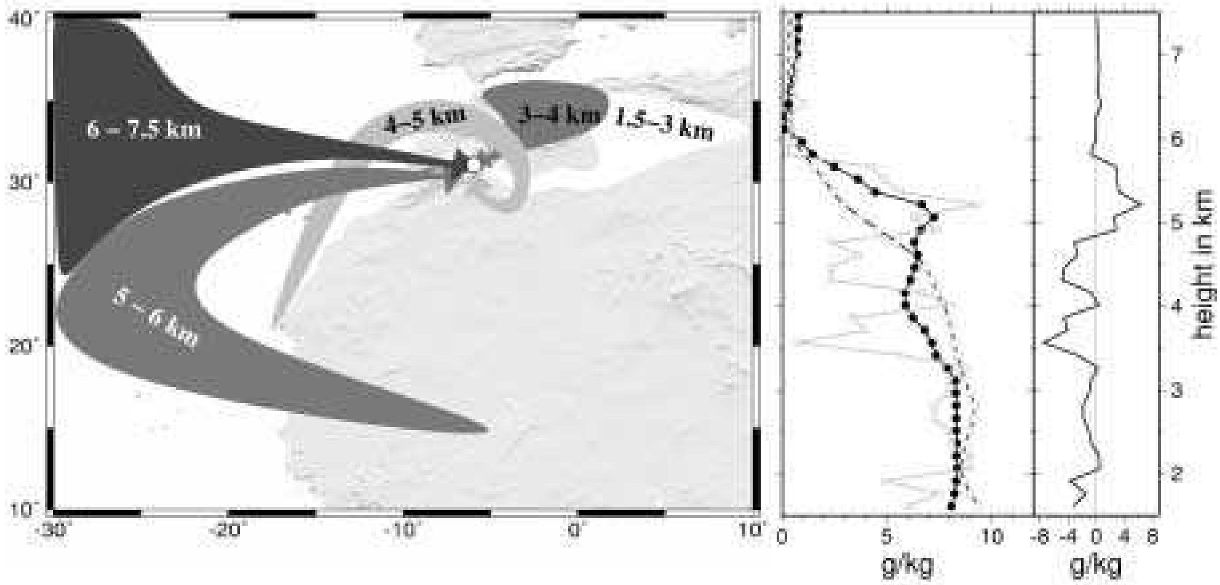

Fig. B1-2: The LM case study of a thunderstorm on Aug 25, 2001. Left panel: Conveyor belts with corresponding heights constructed from 84 h backward trajectories at 6°W, 31°N. Right panel: Profiles of specific humidity (i) thunderstorm (white circles), (ii) parcels on backward trajectories 6 hours before (black circles) and (iii) 60 hours before (squares, grey). Right part: differences between 60h backward trajectory-profiles and thunderstorm (curve iii minus curve i). This shows that the pre-storm moisture maximum in 5-6 km height is clearly of tropical origin.

Investigations with FOOT3DK (cf. A1) focus predominantly on evaporation in the mid and lower Drâa valley as an important sink for freshwater. For this purpose, FOOT3DK is nested into the Lokalmodell (LM). The influence of a flood wave that leads to saturated soils in the Drâa oasis, the effect of transpiration of deep rooting plants and the benefit of improved soil masks on evaporation and the atmospheric circulation have been tested. The model reacts with pronounced sensitivity to all factors. In particular, soil moisture and transpiration changes exert a remarkable influence on the near-ground atmospheric flow that can even lead to changes in occurrence and efficiency of the isolated moist convective events in the region. The results underline the need for accurate surface and initial soil moisture data. The corresponding database is currently improved in subprojects B2 and B3. With accurate surface and soil data, FOOT3DK will be used as a viable tool to calculate area-covering fields of evaporation and related meteorological quantities on high resolutions up to a few 100 m. This information will contribute to an accurate determination of the water budget in the Drâa.

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01.05.2000-30.04.2003

WATER AVAILABILITY AND SOIL DEGRADATION

B. Diekkrüger[1], S. Cappy[2], B. Chafik[3], M. Gumpert[1], B. Reichert[2], O. Schulz[1], A. Skowronek[3], J. Thein[2], B. Weber[1], M. Winiger[1]

[1]Geographische Institute, Universität Bonn, Meckenheimer Allee 166, D-53115 Bonn
[2]Geologisches Institut, Universität Bonn, Nußallee 8, D-53115 Bonn
[3]Institut für Bodenkunde, Universität Bonn, Nußallee 13, D-53115 Bonn
b.diekkrueger@uni-bonn.de; http://www.uni-koeln.de/globaler-wandel/impetus/

Key words: climatology, soil water, snow cover, soil degradation, hydro-geology, hydro-chemistry

Abstract:

The aim of this project is to analyse and to quantify the climatological, hydrological, geological, and pedological processes in the investigated arid catchment. Eleven weather stations were installed at test sites situated along a gradient of aridity and elevation chosen in close co-operation with the subproject B3. Detailed small scale investigations were carried out at the test sites in order to gather process knowledge required for developing and applying hydrological simulation models. Small scale soil mapping is performed and soil degradation is monitored using erosion pins and sediment traps. The test site concept is the base for the regional characterisation of the whole catchment necessary for predicting the effect of global change on the hydrosphere.
In the High Atlas the spatial and temporal dynamic of the snow cover is investigated because it is the most important water resource for the reservoir at Ouarzazate and therefore for the middle Drâa catchment. The analysis is carried out by combining remote sensing techniques with field observations. Groundwater quality and quantity is monitored at numerous wells and springs. These data were combined with information about the isotopes $\delta^{18}O$ und $\delta^{2}H$ and detailed information concerning the geological structure to quantify the groundwater reservoir and their temporal dynamic.

Results:

For a detailed description of the weather at the test sites, eleven weather station were installed. All stations were equipped with sensors for rainfall, temperature, relative humidity, radiation, wind velocity, soil matric potential blocks etc. Four stations were additionally equipped with TDR sensors to monitor the soil water content. Where possible discharge gauges were installed to measure runoff.

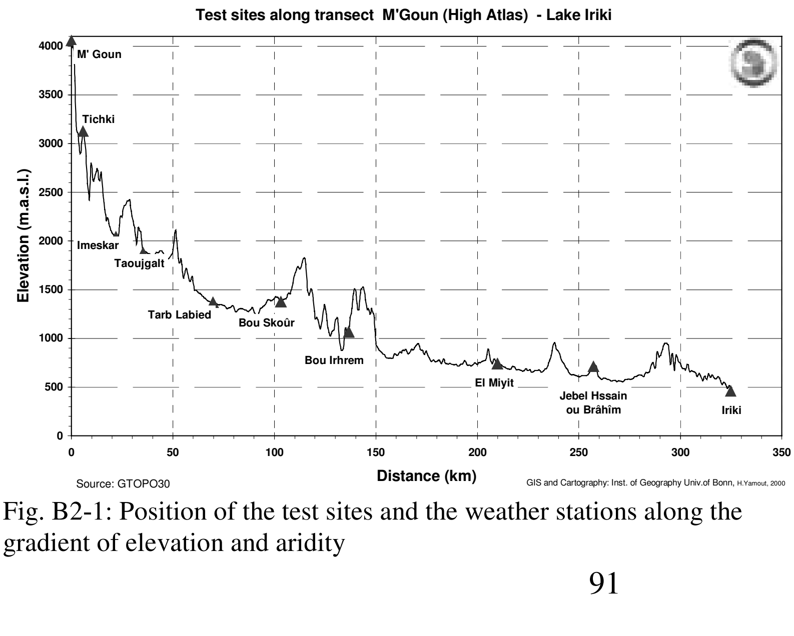

Fig. B2-1: Position of the test sites and the weather stations along the gradient of elevation and aridity

As an example for the analysis of the weather data obtained from the weather stations the wind and rainfall

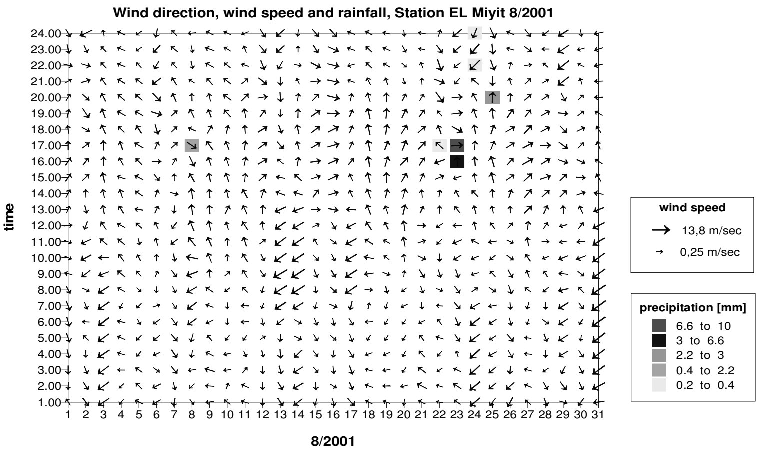

Fig. B2-2: Wind direction, wind speed and rainfall in El Miyit, August 2001

situation August 2001 at El Miyit is shown in Fig. B2-2. The synoptic wind can not be derived from local wind measurements because a small scale wind system near the soil surface is visible. Knowledge concerning these local wind systems are important to understand rainfall patterns controlled by luff-lee effects. In total 12.8 mm of rainfall were observed in August. Comparing these data with a near by rainfall station and satellite images the importance of local thunderstorm is apparent.

The determination of the water quantity stored in the snow cover at the regional scale can only be accomplished by using satellite images. As an example the calibrated and geo-referenced NOAA-AVHRR images were used for testing different approaches for snow mapping: Normalised Difference Snow Index, classification according to the "Parallel piped" and the "Maximum Likelihood" method. The snow maps given in Fig. B2-3 were calculated considering the following three steps:

1) Normalised Difference Snow Index (NDSI) > 0 [NDSI = VIS – MIR / VIS + MIR], 2) channel 5 (TIR) > - 10°C, and 3) channel 2 (NIR) / channel 1 (VIS) < 0.

For validation a Landsat 7 ETM image was used. Although calibration of thresholds were necessary in this procedure the derived maps do show high reliance. A detailed validation of the procedure will be possible by using data from the weather station installed in the High Atlas because they are equipped with automatic snow gauges. Numerous soil temperature data logger were buried in order to determine the spatial and temporal pattern of the snow cover. For simulating the dynamic of the snow cover a modified version of the Snowmelt Runoff Model (SRM, Martinec et al. 1998) will be applied. Because SRM is based on the degree day method, an energy balance approach actual under development in co-operation with subproject B1 will be more promising.

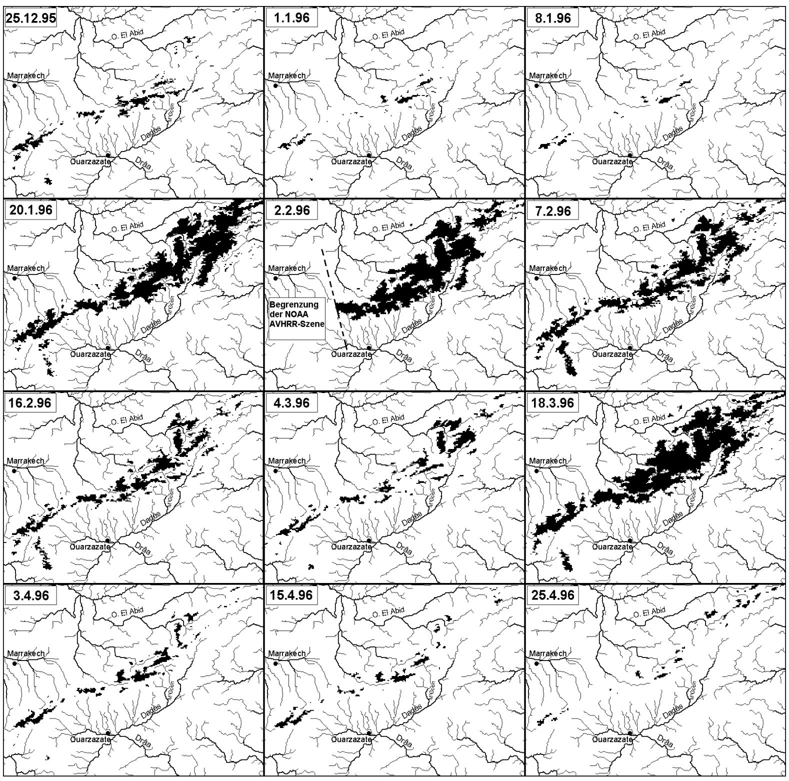

Fig. B2-3: Snow maps of the High atlas derived from NOAA AVHRR satellite images recorded winter 1995/96

The hydrological situation in the catchment is characterised by small scale variability of soil properties and vegetation coverage. The soils layer is generally thin, often only a few centimetres at the hill slopes. Infiltration, evaporation, and soil water storage is strongly influenced by the high content of stones. While the effect on soil water storage can easily be determined, the consequences for evaporation and infiltration has to be studied in detail. Therefore, an evaporation experiment was started according to the approach of van Wesemael et al. (2000). According to these experiments, evaporation rate is 3 to 5 times lower in soils with a stone coverage compared to pure soils. Furthermore, losses were lowest when the stones are not isolated at the top but enclosed in the soil matrix. The stone content causes large problems in determining the infiltration behaviour. Therefore a rainfall simulator was constructed (see Fig. B2-4). Although the effort in determining infiltration capacity is high, the results are promising. As an example the runoff measured at the test site Bou Skour is given in fig. B2-5. Ponding is reached very fast, the final infiltration rate is already achieved after 15 min. In order to characterise the test sites, hydro-pedological mapping is performed according to the approach of Lange (1999). By measuring soil properties for each hydro-pedotope (soil texture, stone content, infiltration capacity, water holding capacity, etc.) the important information required by the simulation model were determined.
The simulation model applied in this project is a new development based on the work of Lange (1999) and Boer (1999). The grid based model computes soil temperature, evapotranspiration according to the Penman-Montheith approach, soil water dynamics using a simplified two layer concept, infiltration by the Hortan approach and runoff concentration with the Mannings formula. The model is actually tested using data from the southern test site El Miyit. After successful application to the test sites the model will be generalised for application to larger scales.
For the application of the model an accurate digital elevation model (DEM) is required. For three of the test sites DEMs were generated using a differential GPS, for the other this will be performed during the field campaign spring 2002. For larger areas a DEM was derived from digitised topographical maps.

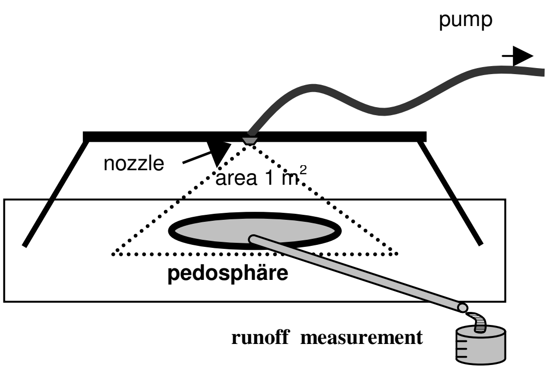

Fig. B2-4: Rainfall simulator used for determining infiltration behaviour (nozzle Veejet, Spraying Systems Co.)

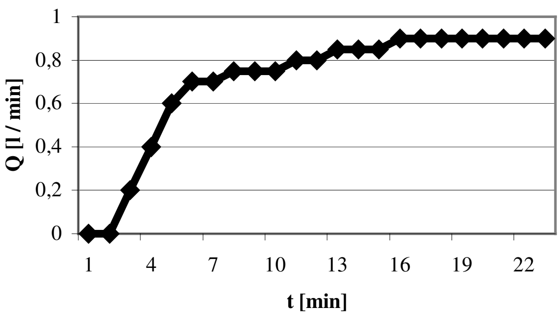

Fig. B2-5: Measured discharge at the test site Bou Skour (stone coverage > 80%) Rainfall intensity was 1.5 l/min, ponding occurs after two minutes

Because no soil maps were available for the investigated catchment, a detailed soil mapping (about 100 soil profiles) was performed. In co-operation with the hydro-pedological mapping, soil probes were taken along different soil catenas. Soil type as well as soil texture, salinity, organic matter content etc. were determined and stored together with relief properties (slope, slope length etc.) in a database. This database is required for deriving soil-relief-land use relationships which will be used for the regionalisation of the soil properties. From the field observations the fundamental relevance of the vegetation for the small scale variability of soils is visible. Vegetation acts as a sediment trap and is therefore important for soil conservation. At the test site Tichki about 4 l of soil per m^2 were trapped in the vegetation at the upper slope and about 8 l soil per m^2 at the middle slope. Because the texture of the trapped soil as well as the soil depth differ between vegetation covered and vegetation free zones the small scale spatial variability of soil water and runoff behaviour is closely linked to the vegetation dynamics. Therefore, detailed experiments were carried out in close co-operation with the subproject B3. In addition to the soil mapping soil erosion measures were installed at selected sites. The combination of the results from sediment traps, erosion pins with map of the erosion damage will be the base for the erosion assessment.

The investigation of the hydrogeology focuses on the upper Drâa catchment in the first phase. Because only a rough geological map is available, a detailed geological mapping of the test sites situated in the High Atlas and in the basin of Ouarzazate was performed. This mapping at the local scale results in detailed knowledge concerning the hydrogeological classification of the test sites and their related springs and wells. As an example, fig. B2-6 shows the hydrochemical classification of the groundwater in the testsite Ameskar, High Atlas, which is determined by the geological situation. Some springs are characterised by a distinct mixing of the general clearly geogene determined water types (e.g. basalt, carbonates). Mixing portions show a distinct dependence on the hydraulic situation. However, the hydrochemical pattern could not be used to solely determine the catchment area of the springs. Therefore environmental isotope measurements have been performed in the northern Drâa catchment area, showing a reasonable correlation of $\delta^2H/\delta^{18}O$-data with the meteoric water line (Fig. B2-7: MWL: $\delta^2H = 8\ \delta^{18}O + 10$ ‰). Deviations are partly due to enrichments by evaporation effects. Based on the rare rainwater data available no local input function for the $\delta^{18}O$- and δ^2H-content of the rainwater could be established so far. However, the regular sampling of rainwater started in autumn 2001. Therefore a determination of the various catchment areas of the springs will be performed soon.

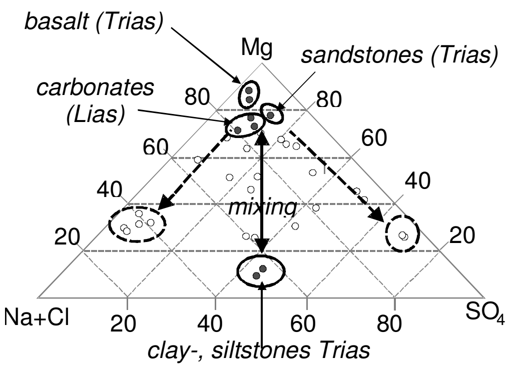

Fig. B2-6: Triangle diagram of selected springs of the test site Ameskar

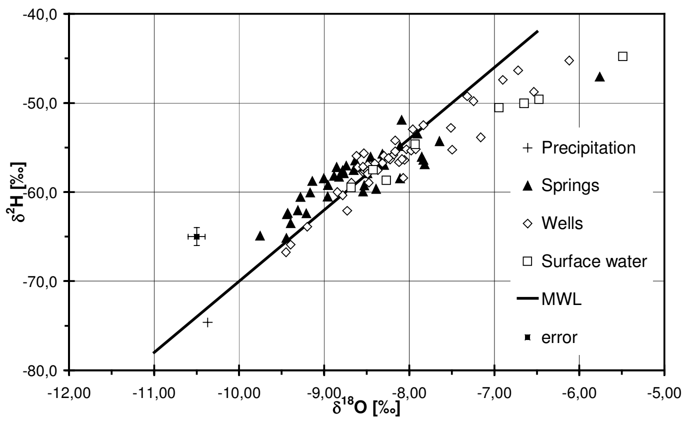

Fig. B2-7: Analysis of the isotopes of all investigation sites of the upper Drâa catchment. MWL = meteoric water line

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1.5.2000 - 30.4.2003

FUNCTIONAL RELATIONS BETWEEN VEGETATION DYNAMICS, WATER CYCLE AND HUMAN INFLUENCE

N. Jürgens[1], J. Burkhardt[2], M. Finckh[1], H. Goldbach[2], F. Gresens[2], G. Menz[3], M. Schmidt[3], M. Staudinger[1]

[1]Institut für Allgemeine Botanik, Universität Hamburg, Ohnhorststr.18, D-22609 Hamburg
[2]Institut für Agrikulturchemie, Universität Bonn, Karlrobert-Kreiten-Str. 13, D-53115 Bonn
[3]Geographische Institute, Universität Bonn, Meckenheimer Allee 166, D-53115 Bonn
j.burkhardt@uni-bonn.de

Key words: Remote sensing, land cover classification, vegetation dynamics, permanent monitoring plots, spatial related evapotranspiration, resource management

Abstract:

Subproject B3 deals with vegetation-based regulating mechanisms which control the regional water balance. The selected approach is based on the coupled spatio-temporal pattern analysis, and integrative process oriented methods to assess the regional evapotranspiration. Finally, research is oriented towards investigations on the technical aspects of water efficient crop management and sustainable pastoral land use systems.

Results:

Organisational progress

During the first project phase, the logistic infrastructure of the subproject B3 was completed. Ten fencing experiments and 34 permanent monitoring plots (PP) have been established along the IMPETUS-Transect. Each permanent plot covers an area of 100 m². The census units are ¼ m², the data refer to the rooting point of an individual plant.
The floristic exploration of the study area has proceeded successfully. 150 vegetation relevés were established in the upper and middle Drâa-Catchment. Each plot is geo-referenced and linked to the GIS of the study area.
In co-operation with ORMVAO, a weighing lysimeter and a climate station were installed at the oasis of Zagora (Asrir) in order to measure evapotranspiration (ET) in arable lands.

Analysis of spatial patterns in landscape and vegetation

Macro-scale: The spatial distribution of different land use and land cover categories of the Drâa catchment were derived from LANDSAT-ETM data, by means of a hybrid supervised classification. This necessitated the collection of land cover and land use parameters from representative observation points (e.g. vegetation coverage, ~height, ~composition, spectral reflectance and estimation of leaf area index). Linear Spectral Unmixing, Maximum Likelyhood and Knowledge Based Classification were applied to the LANDSAT-ETM-data. The overall accuracy of the first classification result is 90 %.
The first classification of the relevés gives an explicit trisection of the vegetation, and it's affiliation to three floristic regions in the study area: Mediterranean vegetation on the slopes of the High Atlas, and the northern slopes of the Antiatlas, Irano-Turanian steppes in the basins, and finally Saharan vegetation units from the Antiatlas down to the Algerian border.

Micro-scale: At the spatial scale of the test sites, a structural and functional analysis of vegetation patterns has been started. At several test sites, vegetation was mapped at an individual level, using a transect approach with a differential GPS. An elevation model, with high resolution has been compiled. Hence, the spatial distribution and patterns of different taxa, with regard to their ecological affinities, could be analysed. This approach enables the transfer of insights that are acquired from the permanent plots to the landscape level.

Analysis of vegetation dynamics

NOAA-AVHRR-data: In order to analyse the seasonal dynamics within the vegetation in the study area, daily NOAA-AVHRR data were downloaded from the NOAA Satellite Active Archive (starting 01/1999). Using the software TERASCAN, an automatic processing chain was developed for the necessary pre-processing of the data, including geo-correction and calibration. Also, the Normalised Difference Vegetation Index was calculated on a daily basis. NDVI images are used in order to observe the response of the vegetation to rainfall.
LANDSAT-CORONA-IKONOS: In order to carry out a comparative calculation of the reflectances of LANDSAT-MSS (1974), LANDSAT-TM (1987) and LANDSAT-ETM (2000) images, a radiometric and topographic normalisation had to be applied to the data. Ground control points in x, y and z co-ordinates for the geocoding of CORONA and IKONOS images were recorded by means of a differential GPS. High resolution digital elevation models for two test regions were generated out of CORONA stereo data.
The preliminary results of the land use change studies show interesting increases in vegetation in the irrigated areas north, and north-west of Zagora, while in other sections of the Drâa, a significant decrease in vegetated surfaces could be detected.
Monitoring plots: Parameters recorded for each individual plant inside the PP comprise: increase in biomass, frequencies of flowering and fruiting, as well as germination and mortality. The inventaries of the PP can be mapped at the scale of individuals (Finckh & Staudinger, in press). They offer the opportunity to detect hardly noticeable long-term changes, either due to varying physical conditions, or due to different grazing intensities in the ten selected ecosystems of southern Morocco. As vegetation structure influences infiltration, run-off and ET, evaluated data from permanent plots are indispensable in order to properly model the regional water balance.

Vegetation parameters, controlling the regional water balance

Measurement of ET: ET measurements are carried out with different combined measurement systems. A leaf wetness sensor (RESI) was applied for the recording of the diurnal transpiration dynamic of a species. The absolute transpiration rates were attained by calibrating these date with a porometer (LICOR). This approach will be repeated in different seasons so that the seasonal transpiration rhythms of each plant species can be documented. Further information on the potential transpiration, water stress situations and the water stress modulation system of these species will be derived by measuring the actual water potential with a Scholander pressure chamber. The ET of dominant plant species and of different crops that are grown in the Oasis of Zagora are measured at the test sites of El Miyit and Taoujgalt. Oasis ET will also be measured with a weighing lysimeter. It is planned to evaluate the water consumption of selected trees and shrubs with a flow meter.
Determination of biomass: Finally, the biomass of dominant plant species was determined in order to extrapolate the transpiration rates (gathered from single leaves) from the individual to the landscape level. Therefore, the dimensions of randomly selected individuals were determined. Subsequently, these plants were harvested. The transpiring and non-transpiring biomass was separated. For each of the dominating species, a calibrated transpiration-biomass curve will be calculated. In combination with the vegetation maps of the permanent plots and the test sites, the area related transpiration rate of the stands can be determined efficiently.

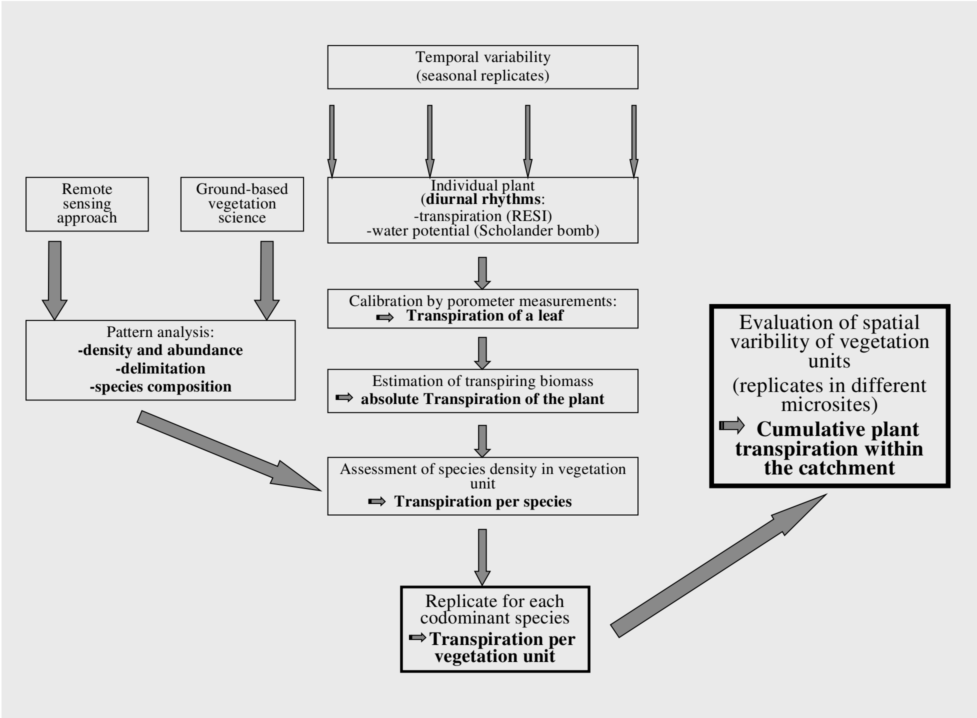

Fig. B3-1: Spatial related evapotranspiration

Development of resources management tools

With regard to IMPETUS´s aim to develop efficient and sustainable resource management plans, the subproject B3 aims at developing concepts for water-saving pastoral and agricultural techniques. Hence, the initial focus has been put on restoration techniques.
Plant establishment with hydrogels: Hydrogels provide a possibility to increase the soil water storage capacity and to minimise evaporation. We will try to use hydrogels for plant establishment on eroded soils. This procedure might support the restoration of degraded rangelands.
At first, greenhouse experiments with two different polyacrylates (HYSORB, STOCKOSORB) and one silicate (BETASOIL) were carried out. Subsequently, field experiments were started at two different locations in Morocco. A local variety of winter wheat is cultivated at the field station of Asrir and experiments with *Atriplex halimus* are running. Finally, *Citrus limon* saplings are used for a pot experiment with nine replicates. Preliminary results indicate that the treatments with polyacrylate-based hydrogels perform better under water stress than those with the silicate gel.
Rangeland management: Rangeland degradation due to overgrazing and firewood collection is the main ecological problem in these areas. Therefore, as a first approach to quantify impacts of pastoralism on the vegetation, ten enclosure experiments have been installed. The comparison of coupled PP inside and outside the fenced areas allows the evaluation of grazing impacts on biomass production and species composition. Depending on the results derived during the first phase, we will initiate controlled grazing experiments in the next phase, in order to define the carrying capacity of the different ecological units.

Perspectives

We are intending to establish stand ET balances at selected test sites during the remaining time of the first phase.
The monitoring of the permanent plots has to be continued in order to assess the impacts of climatic variability and changing land use patterns. A preliminary vegetation map of the Drâa

catchment will be completed by the end of the first project phase. In the second phase, vegetation classification and cartography will be refined to a higher resolution, thus, serving as a basis for spatially orientated vegetation modelling.
Temporal aspects of long and short-term vegetation changes will be analysed over time and space, using multi-temporal sequences of different remote sensing media. This method will support the measures to identify the driving forces of degradation and desertification.

Links to other subprojects and research groups

Field experiments are carried out in close co-operation with the local population. Links have been established with the *Institut Agronomique et Vétérinaire Hassan II* and other Moroccan research institutions. We are also co-operating with the projects *ROSELT* and *PBTHA* (*Projet de Biodiversité et Transhumance dans le Haut Atlas*). The RSRG is co-operating with Prof. Goossens from the University of Gent (Belgium) and with Dr. M. Canty (FZ Jülich). Close contacts exist with the BIOTA-project, especially, with regard to methodology and technical co-operation.
Our strong transdisciplinary research link with the socio-economic subproject B4 is based on determining the long-term demographic trend, survival strategies and economic development of mobile pastoral groups with regard to land use and grazing pressure. These key factors ultimately affect the vegetation dynamics. Currently, in a joint initiative with the GTZ (Zagora), the human impacts on the Tamarisk forest west of M'Hamid are being investigated as well. Interdisciplinary activities are also being carried out with the subproject B2, with regard to aspects of infiltration, run-off and microclimatic conditions.

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WATER DISTRIBUTION AND WATER CONFLICTS

M. Casimir[1], B. Casciarri[1], H. Kirscht[1], C. Rademacher[1], M. Rössler[1], D. Schlütter[2],

[1]Institut für Völkerkunde, Universität zu Köln, Albertus-Magnus-Platz, D-50923 Köln
[2]Geographische Institute, Universität Bonn, Meckenheimer Allee 166, D-53115 Bonn
http://www.uni-koeln.de/globaler-wandel/impetus

Keywords: water management, water rights, water conflicts, water distribution, socio-economic development, institutions, water use, irrigation

Abstract:

The aim of the B4 sub-project is to analyse the water distribution and water use in the Drâa valley in Morocco. Local land and water rights have to be identified, described and related to the power-position of various social groups involved. Social stratification along ethnic, tribal-agnatic or economic lines is common in most of the communities. Water distribution often is organised according to this stratification of society, which can be demonstrated in various settings along the Drâa valley. Although local water distribution systems are still functional in many rural settlements, modern influences like labour migration or tourism haven altered the traditional water relations in the urban context, but also in some rural areas. To cover the full range of cultural variations of the water use systems, the research area of the anthropological work-package was extended. After the first half of the ongoing research period areas in the middle and upper Drâa valley were included.

Results:

<u>Dynamics of socio-economic change in water management among agricultural and pastoral communities in the southern and middle Draa valley</u>

The sedentarisation process and the interplay between nomads and sedentary groups; the dynamics of tribal institutions; the strategies of domestic groups in water distribution

Ethnological fieldwork mainly focuses on the socio-political dynamics of pastoral and sedentary groups in the southern Drâa valley. The access to, the distribution of, and the conflict over natural resources - especially water and land - are analysed. Three groups are the object of the inquiry in the Ktawoua region: 1) The "persisting nomads" who mainly belong to the Aït Unzâr tribe, a sub-fraction of the Aït Atta Berber confederation; 2) The former nomads who settled in marginal quarters of the urban centre of Tagounite since the mid-70s; 3) The mixed population of Arab-speaking Draoua farmers and Berber-speaking Aït Unzâr pastoralists, who settle in the *ksar* Tiraf, in the extreme south-west of Ktaoua Oasis.

In Tiraf, the access to water still seems to be managed along traditional social and status categories. The basic division remains the one between Draoua and Berbers. This becomes obvious in: 1) the organisation of the distribution of drinking water at the collective taps in the *ksar*; 2) the lineage-based partition of water rights for irrigation; 3) the limitation of water rights concerning wells outside the cultivated space of the oasis; 4) the solidarity networks based on ethnic, tribal-agnatic or status identities. This persistence of a well-rooted social background does not neglect social mobility, often linked to migration and the spreading of capitalist labour relations.

The importance of local institutions in managing the socio-economic life is underlined by two features: The "harmonious", non-contradictory coexistence of national "modern" state elected functionaries and traditional tribal non-elected representatives in local administration on one hand, and the relevance of an interplay between Aït Unzâr nomads and the sedentary tribal groups of the Draoua in managing all daily matters on the other. This is well illustrated in the vitality of the two tribal assemblies in Tiraf, representing and organising their respective groups. In a context of spatial and socio-economic marginality, the existence of such autonomy and capacity of "bottom-up" management is particularly important as a counterbalance to state institutions as the AUEA.

A more quantitative analysis based on demographic and socio-economic data showed a number of issues and a remarkable flexibility in the distribution of the household tasks to cope with drought and crisis. Nomads and former nomads differ from the established sedentary population in choosing different economic strategies, nomads being most oriented towards military service, while the latter are more attracted by labour migration and investments in education. Marriage patterns also offer an interesting insight into strategies of adaptation to rapid changes and resource scarcity.

Strategies of water acquirement in a village of the middle Drâa valley

Fieldwork was done in Blida, a village on the left edge of the Southern wadi Drâa. The work focused on the socio-political life and the local institutions in the village as well as on the availability and distribution of water resources. The village has about 113 households. Its population consists of the following five social groups 1) *Ait Isfoul,* 2) *Draoua,* 3) *Reggaga,* 4) *Abid* and 5) *Chorfa*. Life in the village is characterized by strong social, political and economical hierarchies. In Blida, the water situation of an individual, a residential or descendant group is closely related to the power-position occupied in this socio-economic structure.

Water in Blida is available in various forms: water pumps (wells), water reservoirs *matfia*, and river water. Water is distributed according to the local water rights *nouba*. Having access to these water-sources depends either on the rigid "local" water law, on the economic power, or on the social networks between and within the social groups. Irrigation water comes mainly from the *Mansour Edhahbi* dam. It is distributed through the "local" canalisation, the *seguia.* Branches of the *seguia* that lead to the plots of irrigated fields are named after lineages living in the village. Farmers who need water for agricultural production but who are not entitled to *nouba* rights have only few options. They can either dig a well and install a water pump, or buy water on an hourly basis from other farmers owning a water-pump. The scarcity of the irrigation water necessitates the co-operation of social groups, or urges individuals to seek a patron/client relationship. Because of the salinity of most wells, drinking water for almost all the social groups is provided by the dam. In some cases, the water of wells having the best water quality is also used as drinking water.

To participate in decision-making processes all social and descendant groups are represented in the *qabila*. The position of *sheikh*, which is nowadays a governmental position, has always been held by members of the same descendants group. Decisions related to water are mostly made by these local institutions, although the AUEA was officially created by the government to manage and control water distribution.

Recently the research area has been extended to include another oasis north of the areas already studied. In the palm grove of Tinzuline, anthropological research focuses on the household economy of the mixed population. In addition, the influence of state or para-state organisations on local water distribution systems is being studied.

Urban and rural water users

Changes of water management in the upper Drâa valley

Different institutions and administrative bodies are involved with the water management in Ouarzazate. Conflicts between water users and these institutions can be observed on several levels:

On the large scale, growing competition between urban and rural water use is visible. Due to the population growth and the urban development, the demand for drinking water is rapidly increasing in Ouarzazate. The water of the dam Mansour Ed Dahbi, which should supply water for irrigation in the lower Drâa-Valley, is used to satisfy the urban needs. Although the water consumption for urban purposes is rather low, compared to the annual evaporation, after long dry periods, the water of the dam Mansour Ed Dahbi gets scarce. The actual situation in the fourth dry year in sequence, is marked by the absence of irrigation water for annual cultures like maize, henna and lucerne. The irrigation campaigns could only support the permanent cultures like date- and almond tress and recharge the groundwater.

On the small scale a difference in the access to, and the quality of the drinking water supply in Ouarzazate is evident. In the traditional rural quarters of the town not all households have access to the public water supply. In two rural quarters at the eastern outskirts access is restricted to two hours a day. The drinking water quality declines during the dry season in the areas north of the riverbed. The quality is constantly good in the areas south of the oued. The people react on the poor water quality during the dry season by looking for better drinking water facilities on the other riverside or at springs or wells.

The poor water quality in the dry season results from the absence of a sewage plant for the waste-water of the city. The waste-water is used without treatment for irrigation by the farmers downstream, who have their fields near the outlet on the northern river terrace. The local water supply authority ONEP is an institution with an autonomous budget. After the construction of the treatment plant and the high running costs for the filtration, the authority was forced to expand their distribution net and to sell as much water as possible. The economic use of water is not their major interest, but the balance of the budget. For private households and the administration, the water price is increased with a growing consumption. The major consumer - the industrial sector - has a fixed price.

In the region of Ouarzazate not only the water use and the water distribution has changed, as a result of the socio-economic development, but also the symbolic value of water as a scarce and precious element. Water is now considered as a modern, commercial good, which can be bought, sold and wasted.

Changes of water management in the upper Drâa valley

Conflicts and modes of regulation in the Higher Atlas Mountains

In this work package water distribution systems were analysed and related to arising conflicts and their modes of regulation in the context of social and political upheavals. The research area is located at the foot of the Taskka Zat mountains and is inhabited by several fractions of the Tdili, a Berber group. The intensified cash crop production together with significant investments of migrant workers led to an increase of social differentiation in rural communities and an alteration of the traditional water distribution systems. Beside the, at least temporary, shortage of water, the introduction of motor pumps enabled an intensification of irrigated farming independent of the traditional water distribution system.

Most conflicts in the rural communities arose from the problems associated with the supply of drinking water. The construction of reservoirs and pipelines exhausted the financial means of many communities and damaged the village solidarity. Fractions of the rural population with access to financial support from migrant workers, build houses with modern sanitary installations consuming much more water, than an average household. Although prices for drinking water are graduated - higher consumption means higher cost per m^3 - the feeling of inequality or injustice persisted. In addition, all the expensive reservoirs could not guarantee a continuous water supply. The increase in population, beside the high water consumption of some elaborated household, created a rapidly rising demand in drinking water.

The decline in available water also affects the agricultural sector. As a consequence cultivation of summer crops such as maize and potatoes did not take place in the last years. Again, the failure of summer crops did not affect all households in the same way. While households with access to money from migratory workers could compensate the loss, members of poorer families were forced to work as day labourers of the fields of large landowners. In years with low rainfall, when the demand for farm labour was low, the pressure to migrate outwards was high.

In order to examine the significance of these findings, a second research area west of Toundout in the Imidirt valley was chosen. Current research focuses on the impact of the regional administration of Ghasset and Toundout on the local political actors. Moreover, anthropological research about local knowledge systems is carried out in the vicinity of some botanical research areas. These studies aim at comparing scientific and local concepts of knowledge about natural resources.

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INTEGRATION IN THE GLOWA VOLTA PROJECT: FROM CONCEPT TO FEASIBILITY

P.L.G. Vlek, N. van de Giesen

Center for Development Research (ZEF), Bonn University, Walter-Flex-Str. 3, 53113 Bonn, Germany
p.vlek@uni.bonn.de, nick@uni-bonn.de, http://www.glowa-volta.de

Keywords: Integrated watershed management, global change, hydrological cycle, West Africa

Abstract:
Integration in the GLOWA Volta project is a means to an end. The end is to establish a decision support system (DSS) for water management that is scientifically sound and can be readily used by decision makers in the region in order to optimize water allocation between regions and sectors. Economic, social and natural science issues will have to be brought into the analysis. The GLOWA Volta project makes it its primary task to insure that this is done from the onset as can be seen from the diagrammatic presentation of the project in Figure 1. In the following chapter we highlight some areas where integration of various disciplines has been accomplished in innovative ways, demonstrating the validity of addressing the integration issue early in the project. The chapter closes with a short description of the infra-structure that was needed for the implementation of the project.

Results:

The overall goal of the GLOWA Volta project is to develop, in close collaboration with our partners in Ghana, a tool (Decision Support System) that will help the authorities in Ghana, and later Burkina Faso, to optimize water allocation within the basin. The art of water allocation is to properly and equitably account for the various economic development interests of the region while insuring that the ecosystems that depend on this resource are not threatened. This should be done with the recognition that water availability may change under changing global climate conditions. This Status Report covers progress made in the first 20 months of the GLOWA Volta project. The report is divided in an overview section and three parts presenting more in-depth results. Here in the overview, we focus on ***Integration*** and ***Infrastructure*** development.

Integration

Understanding the complex relations between the water cycle, climate, and economic development requires insights from many scientific disciplines. The real challenge of the GLOWA program is not only to collect information using the various means and methods of these disciplines, but above all to tie all this information together in a meaningful and quantitative way. The sources, type and coverage of the data were discussed at length in our 2001 Year Report. In this status report, we emphasize the progress we made in scientific integration of this multi-faceted information.

As the project scientists have noticed over the past two years, bridging different disciplines comes at great transaction cost. Explaining one's own and exploring someone else's scientific possibilities and limits is prone to misunderstanding, and it is time consuming and frustrating at times. Scientific integration must add value in order to be justified. We identified three integrative focal points where added value can be gained. In each of these, questions are answers that cannot be addressed by a single science: *atmosphere/surface interactions*, *land-use-change modeling*, and *water-use optimization*. At each of these interfaces, scientists are challenged to collect and manage their information in a way and on a scale so enabling the neighboring disciplines to work jointly with that data and generate additional information. Ultimately, the information forms the basis of an integrated model that can serve as a basis for a decision-support system. The overall integrative structure being used for this purpose in the project is the same as the one in the original proposal.

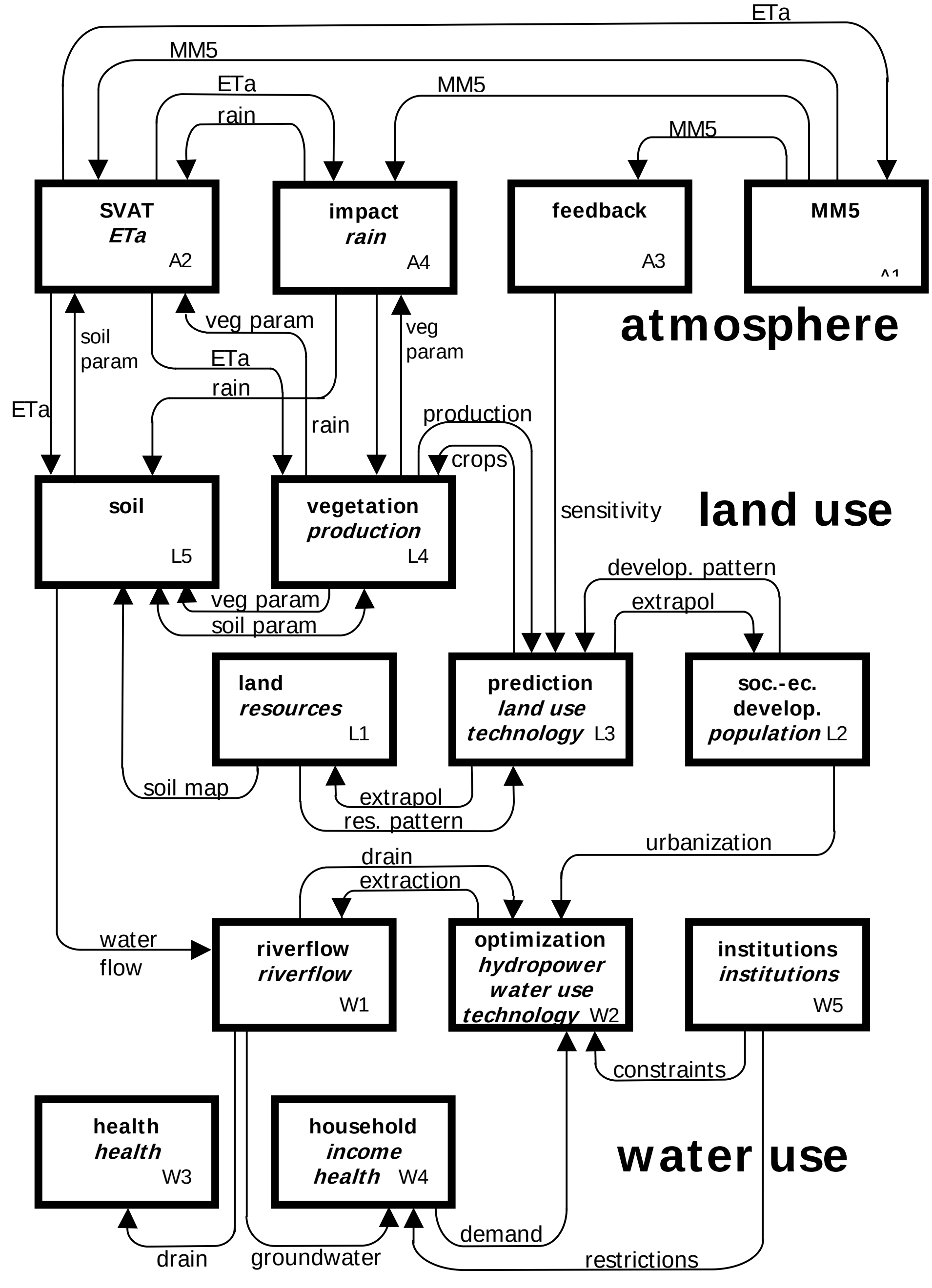

Figure 1: Overview of project structure with sub-project names and codes, information exchange, and state variables (italic)

As a first step, we selected 11 state variables that need to be modeled over space and time in order to describe the development of the Volta Basin (*Rain*, *Evaporation*, *Agricultural Production*, *Land Use*, *Population*, *Riverflow*, *Water Use*, *Hydropower*, *Health*, *Technology*, *Institutions*). In a second step we defined sub-projects that could develop such models, describing the behavior of these state variables. The third step was to identify information needs and define additional sub-projects that could produce that information as intermediate outputs. We organized the sub-projects in three research clusters: atmosphere, land use, and water use. These clusters are not defined along disciplinary lines but coincide with the three main parts of the hydrological cycle. The sub-projects in each cluster serve as the basic planning blocks, associated with specific human and material resources. Most sub-projects are not integrative in nature and basically cover one discipline such as soil science or household economics. The information dependencies between the sub-projects are shown by the arrows in Figure 1. Information exchange mainly takes place between kindred disciplines: the agronomist communicates with the soil physicist, the soil physicist communicates with the hydrologist, etc. The coherence of this network is described below in more detail for each individual cluster in the three sections of the Status Report. First, we present the integrative foci, *atmosphere/surface interactions*, *land-use-change modeling*, and *water-use optimization*.

Atmosphere/surface interactions need to be understood to account for the feedback between climate and change in land-surface properties. Land-use change is the main global change phenomenon within the Volta Basin. The extensive efforts to simulate regional climate change with the MM5 atmospheric model depend crucially on the proper quantification of the effects that these land surface changes have on the atmosphere. The integrative challenge is bridging the gap between meteorology and hydrology. In Figure 1, these atmosphere/surface interactions are represented by the large number of intersecting arrows. Although these natural sciences have much in common, both involving fluid dynamics, phase transitions and massive computational efforts, in communicating with each other they are confronted with a very important scale gap. The smallest grid cell size at which long-term climatological atmospheric simulations with our adjusted MM5 model are feasible is about 9x9km². Most process-based hydrological models are at the scale of a uniform field in case of evapotranspiration or a hill slope in case of runoff. Hydrologists do have models at the watershed scale (>10 km²), but these are either lumped conceptual models or distributed models with a very fine internal resolution of, say, 30x30m. The conceptual models do not have much predictive value because we do not know how, for example, changes in land-use affect the parameters of conceptual models.

What is needed to bridge the scale gap is a method to aggregate measurable physical properties of landscape elements (fields, slopes) into effective parameters at the 9x9km² scale. In some cases, such as albedo, one can simply take a linear average but when it comes to parameters such as surface runoff, evapotranspiration, rooting depth or roughness length, aggregation is much more difficult. We are approaching this problem both empirically and through numerical simulations. We have given priority to dealing with surface runoff and evapotranspiration.

To model surface runoff, rainfall at the 9x9km² grid is first statistically disaggregated based on measurements made at a nested grid of rain gauges. This serves as input into a surface runoff model that is calibrated on the basis of runoff plots of three different lengths to ensure it correctly captures any scale effects. Runoff from the slopes is then summed to give the 9x9km² values. To date, the disaggregated rain measurements, a runoff model, and the runoff plots are in place, but we still need one season of runoff measurements. We also measure the total surface runoff from our experimental watersheds, which helps to test our aggregated surface runoff model and, through the mass balance, puts constraints on the evapotranspiration model.

Evapotranspiration is modeled using the Surface-Vegetation-Atmosphere-Transfer (SVAT) model, developed specifically for the MM5 atmospheric model. We have numerically tested the sensitivity of the model with respect to all parameters in order to better concentrate our parameterization efforts. Great effort went into measuring evapotranspiration at a large, aggregated scale. Scintillometers were installed in each of the three experimental watersheds to measure directly the sensible heat flux over distances of more than two kilometers. By measuring ground heat flux and net radiation, evapotranspiration can be calculated as the remaining term in the energy balance. Because scintillometers measure spatially aggregated heat fluxes, they are our key instruments in bridging the scale gap between meteorology and hydrology. In close cooperation with the Meteorology Department of Wageningen University, we have been able to make almost continuous routine measurements with the scintillometers in West Africa.

Land-use-change modeling (sub-project "L3 Prediction") occupies a central position in the land-use cluster. Clearly, land-use change is the result of social as well as physical factors. This is reflected in Figure 1, where the sub-project "L3 Prediction" receives information from many different sub-projects covering a number of disciplines. In its turn, land-use change plays a pivotal role in affecting local climate and in the partitioning of rainfall between evapotranspiration, and groundwater and surface flow. We are developing in parallel different types of models, from classical multiple-linear regressions to state-of-the-art multiple-agent models that will capture the effect of various processes on the dynamics of land-use change. All models have in common that they are very data hungry. The main integrative progress so far pertains, therefore, to better methods of data gathering.

Land-use change tends to take place unevenly over space and time. As data gathering on the ground is time and money consuming, it makes sense to focus intensive ground campaigns in those areas where change is indeed taking place. We call such areas "hotspots" and we have used a two-tiered identification process. First, we mapped large-scale changes during a land-use workshop based on expert opinion from the region. We then used remotely sensed data to zoom in and quantify specific hotspots. A very important result has been the mapping of the land use and land cover for 1991 and 2000 on the basis of Landsat images using test sets and maximum likelihood classification. The formerly used land-use classification method was based on manual classification, which was prohibitively labor intensive. The present method allows for quick mapping of the complete basin, which is the size of Germany, at different dates (a 1984 map is presently in the making).

Changes in tree densities are expected to have the most profound hydrological impact and special attention has, therefore, been given to this land-cover characteristic both during field research and subsequent classification. The new land-use maps are used to detect changes over the past decades, thereby helping to identify and quantify hotspots. Land-use change in the Volta Basin turns out to be a very dynamic process. Every deforested patch cannot simply be equated with land-use intensification because farms and complete villages may have moved over large distances, leaving behind an area under natural reforestation. Two hotspots are currently under intensive ground investigation: Wuripe, southwest of Tamale, where dense woodland is being replaced by agriculture, and the Northeast near Navrongo, where irrigation development is most intensive.

We have the good fortune to have access to the Ghana Living Standards Survey (GLSS) that contains regularly collected standard socio-economic variables such as income, agricultural production, and family composition. The project will model land-use and household water demands. For that purpose additional data on a community and household level are required. Thus, limited surveys concerning variables not covered in the GLSS were undertaken, using a common sampling frame that was developed to link our surveys to the GLSS. First, a cluster analysis of all villages in the GLSS was performed. This analysis included also evaporation and geology as important determining physical factors. From each cluster, one or two representative villages were selected for extensive household and community surveys. Although the survey was mainly socio-economically oriented, soil and water samples were also taken to be better able to capture household decision making in its biophysical context and link up environmental information gathered elsewhere in the project. Finally, a short list of standard questions was developed that identifies the GLSS cluster to which the community belongs. These questions are used by natural scientists, too, for example during ground truthing of the remotely sensed data, and serve as a "social positioning system".

Water-use optimization (sub-project "L2 Optimization") is the central activity in the water-use cluster. Figure 1 shows that economic optimization is subject to hydrological and institutional constraints. As such, it is the third integrative focal point in the project. The water optimization module will be the nucleus of the actual decision support system, which will form the final outcome of the GLOWA Volta project. Because of its importance, it was decided to test the feasibility of linking hydrological and institutional functions in a model early on in the project. We used a standard economic optimization model in which an objective function is maximized. The constraints under which water productivity is optimized can be hydrological and institutional in nature. This early model helps define precise data needs in terms of water supply and demand. The model implements existing integrative knowledge and will gradually be enriched by updated information and new primary data. Presently, the model optimizes over different water uses at thirteen nodes in the river network. The innovation is that optimizations can be carried out at different levels of aggregation. The optimization model has active links to a large set of sub-models that contain auxiliary information such as institutional development scenarios and crop-water demand calculations.

In stereotypical watersheds, hydropower is generated upstream in the mountains and irrigation takes place downstream in the plains. In such cases, water can be used for hydropower without significantly affecting irrigated agriculture. In the case of the Volta Basin, however, hydropower is generated very close to the sea whereas almost all of the irrigable areas are upstream in Northern Ghana and Burkina Faso. Hydropower and irrigation are, therefore, in more direct competition for water. The present model helps make optimal decisions, taking into account different forms of irrigation and alternative energy sources. Even after the first few modeling rounds, the number of links to the optimization module is much larger than suggested by Figure 1. It seems that this relatively straightforward approach to integrating hydrology, institutions and economy allows us to mimic highly complex relations.

Infrastructure

Building scientific and logistic infrastructure for a project is in itself not a scientific accomplishment, but it is included here to give an insight into what is presently possible in Africa. It will facilitate the discussion on future cooperation.

Early on, a project coordination office was established at the Savanna Agricultural Research Institute (SARI), the host institute in Tamale, Ghana. The office coordinates transportation, organizes importation of scientific equipment, and takes care of general and financial administration. The project has six vehicles for transport between and at test sites.

Three experimental watersheds have been instrumented, all of which are in or near hotspot areas. The first watershed is in Ejura, about 80 km northeast of Kumasi. Ejura is representative of the southern part of the basin with higher rainfall (1200 mm/yr) and steeper slopes. Ejura is also an area that has seen many new settlers over the past 20 years. The second watershed lies close to the town Tamale and is characteristic for the central part of the basin with rainfall around 1100 mm/yr and moderate slopes. Land-use intensity in the neighborhood of this large town is high. The third watershed is in Navrongo, close to the northern border of Ghana with Burkina Faso. Rainfall here is about 1000 mm/yr, population density is high, and slopes are flat. Navrongo has a granite geology, whereas the first two sites are underlain by sedimentary rocks. The watersheds have a size of about 15km². At the outlet of each watershed, a flume or weir has been installed with which continuous surface runoff measurements are made. Meteorological stations have been installed, as well as scintillometers that measure sensible heat flux across the watersheds. In Navrongo and Ejura, simple field stations have been set up to facilitate on-going field work by graduate students.

Information exchange is very important in an integrated project. Our website (www.glowa-volta.de) at present serves mainly to keep people from outside the project informed about progress made. It gives an overview of the activities of all staff and students involved in the project, and shows recent progress. It also contains PDF files of most project-linked publications. For internal exchange of large data sets, we have set up an FTP server at ZEF where, for example, all weather data produced by MM5 at the Institute for Meteorology and Climate Research (IMK) in Garmisch-Partenkirchen are stored on a daily basis. Given the poor Internet facilities in Ghana, FTP is also the protocol of our choice for exchanging data and information between Germany and Ghana.

Project ID: 07 GWK 01 (Atmosphere Cluster)
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ATMOSPHERIC MODELING AND INTEGRATION BETWEEN METEOROLOGY AND HYDROLOGY

D. Burose[1,3], J. Friesen[1], J. Intsiful[1,2], G. Jung[2], H. Kunstmann[2], A. Moene[3], P. Oguntunde[1], N. van de Giesen[1]

[1]Center for Development Research, Bonn University, Walter-Flex-Str 3, D-53113 Bonn
nick@uni-bonn.de; http://www.glowa-volta.de
[2]Institute for Meteorology and Climate Research, Section Atmospheric Environmental Research (formerly Fraunhofer Institute for Atmospheric Environmental Research, IFU), Karlsruhe Research Center Technology and Environment, Kreuzeckbahnstraße 19, D-82467 Garmisch-Partenkirchen
harald.kunstmann@imk.fzk.de
[3]Meteorology and Air Quality, Wageningen University, Postbus 9101, 6700 HB Wageningen, Netherlands
arnold.moene@user.metair.wau.nl

Keywords: Meteorology, hydrology, atmospheric modeling, upscaling, energy fluxes, evapotranspiration, downscaling, rainfall, MM5

Abstract:
Understanding feedback mechanisms between atmosphere and land surface is crucial for predicting impact of global change on the regional hydrological cycle. Unfortunately, meteorological models have different scales than hydrological land surface models, which hinders feedback analysis. Results from innovative field measurements (scintillometry) are presented that help integrate hydrology and meteorology by bridging this scale gap. Subsequently, the operationalization of the MM5 meteorological model is described. Numerical experimentation with MM5 shows that changes in land surface properties do have large feedback effects on regional circulation patterns.

Results:
In this part of the status report, from modeling and measurement of the atmosphere and land surface-atmosphere interactions are presented. First, the integration of meteorology and hydrology through downscaling and upscaling is described. Second, results from our meteorological modeling activities is presented.

Integration of meteorology and hydrology
Meteorology and hydrology are closely related conceptually. Both disciplines deal with fluid dynamics and phase transitions and tackle their subjects with highly formalized mathematical tools. Yet, the main issue addressed under this heading is the integration of meteorology and hydrology. Physically, this integration concerns the interactions between land surface and atmosphere that form the feedback between landuse and climate change and are of central interest to GLOWA. As explained in the introduction, coupling the results from both disciplines is hindered by scaling issues in the measurement and modeling of water and energy fluxes. In the GLOWA Volta project, we try to bridge the scale gap through numerical simulations, remote sensing of the distribution of evapotranspiration over space, and through field measurements. Here, the emphasis is on field measurements.
Water and energy fluxes are calculated with the aid of balances. At the watershed level, the water balance equates rainfall to the sum of evapotranspiration, surface runoff, subsurface runoff, and change in storage within the watershed. Over longer periods, the change in storage

is in the West African context negligible compared to the other terms. Rainfall and surface runoff are directly measured at the experimental sites, but subsurface runoff and evapotranspiration are difficult to measure at this larger scale. With the energy balance we can calculate evapotranspiration and subsequently each component of the water balance. The energy balance equates net radiation to the sum of sensible heat flux (the energy that warms the atmosphere), latent heat flux (the energy needed for evapotranspiration), and ground heat flux. Net radiation is generally easy to measure at different scales. Ground heat flux is more difficult to measure at larger scales but tends to be small when compared to the total energy flux and is, in West Africa, close to zero when integrated over a full day. That leaves sensible heat flux and evapotranspiration. If one could measure either at the appropriate scale one can close both the energy and water balances.

There are several ways to measure the energy fluxes at the land surface over larger areas. We chose to measure the sensible heat flux with scintillometers because they are relatively robust and can be operated without intensive expert supervision. A scintillometer measures the sensible heat flux along a line between a transmitter and a receiver. The distance between transmitter and receiver can be up to 5km. Because the measurement integrates over this distance, this technique is very useful for measuring heat flux over complex terrain at watershed level. The transmitter sends an infrared light beam (940 nm) to the receiver. Turbulence causes variation in the breaking index of air and thereby variation in the strength of the received signal, like the scintillation caused by rising air over a hot road surface.

The variance of the logarithm of the intensity of the received signal is a function of the turbulence structure parameter for the breaking index, C_n. C_n is in turn directly related to the turbulence structure parameters for heat, C_T, and vapor transport, C_q. The contribution of the latter to C_n is minimal for the wavelength used which makes calculation of the C_T possible. Once C_T is known, the sensible heat flux can be calculated. Four different algorithms exist to calculate the sensible heat flux from C_n. The algorithms differ in their assumptions concerning the stability of the atmospheric boundary layer and the relative contributions of buoyancy and shear stress to the generation of turbulent energy. Present analysis focuses on selecting the optimal algorithm for different periods using auxiliary data in the context of the Volta Basin.

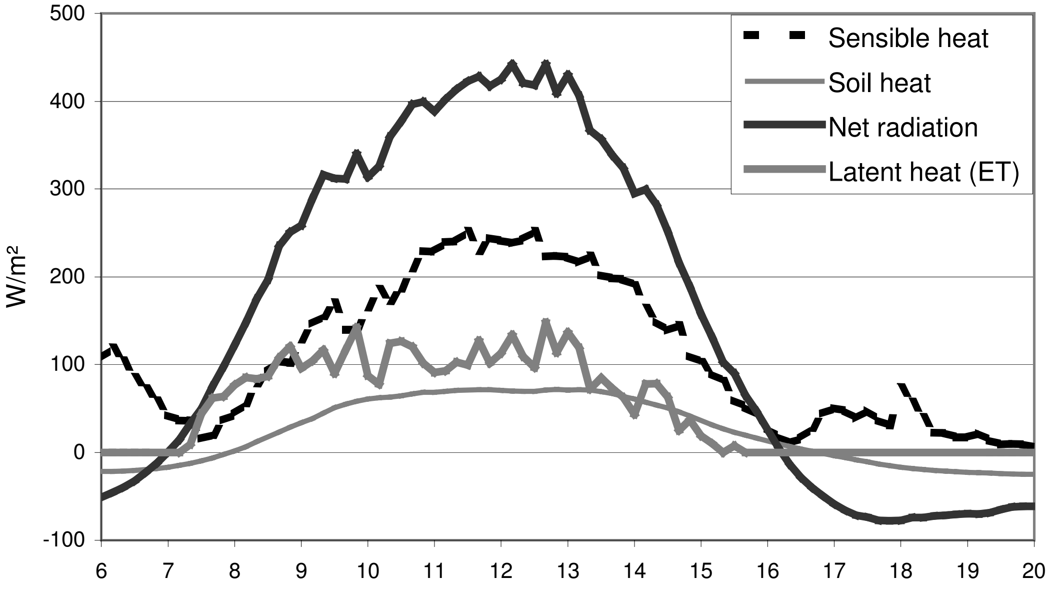

Figure 1: Diurnal changes in energy fluxes for 4 December 2001 at the Tamale experimental watershed

Figure 1 shows a typical daily cycle of net radiation, soil heat flux, latent heat flux, and sensible heat flux. The driving net radiation follows a typical diurnal, sinusoidal pattern, perturbed by some clouds. In this case, the maximum latent heat flux is 150 W/m² which corresponds to an evaporation rate of 5.3 mm/day. Integrated over the whole day, latent heat amounts to 4.35 MJ/m² or an evaporation of 1.8 mm. Most of the incoming net radiation energy goes towards the actual heat flux, warming up the atmosphere. This is typical for this part of the year which is the beginning of the dry season (November through April for Tamale). In November/December there is still some water left for evapotranspiration but the Bowen ratio (ratio between sensible and latent heat flux) is larger than one. During the rainy season, the total incoming radiation is much less due to cloud cover and the Bowen ratio is close to one because there is more water available for evapotranspiration. At the end of the dry season, almost all energy goes towards the sensible heat flux. Over the year, sensible heat flux is almost always significant, implying that evapotranspiration is not limited by the atmospheric demand but by water availability. This is in concordance with earlier findings concerning the water balance for the Volta Basin that showed that more than 90% of the rainfall evaporates. It also implies that all models and measurements that determine evapotranspiration as a rest term in the energy balance have to be precise in absolute terms.

Scintillometers have now been installed in all three experimental watersheds in Ghana. After some initial problems associated with the solar power supply system, the scintillometers are now operated in a routine fashion and provide a continuous stream of high quality data. The exception is during the so called Harmattan winds which bring dense dust clouds from the Sahara to the Northern part of the Volta Basin for a few weeks in the dry season that extinguished the scintillometer beam. We will use these measured energy fluxes for assimilation with fluxes calculated on the basis of remotely sensed data and fluxes modeled by MM5. Clearly, the fact that scintillometers measure at scales comparable to the scales at which MM5 predicts shows the importance of this technique to the overall project.

Given the objectives of the GLOWA Volta project, rainfall is an even more important meteorological variable than surface energy fluxes. Rain is relatively easy to measure at a given point and, with a number rain gauges, also over an experimental watershed. The MM5 weather model predicts rainfall for points at a 9x9km² grid satisfactorily but does not resolve the turbulent dynamics of individual convective rainstorms. In West Africa, most rain is produced by such storms, which show high spatial and temporal variability. For modeling surface runoff and erosion, it is necessary to know rainfall intensities in some detail, at least in the statistical sense. One needs a way to downscale the MM5 output to rainstorms that have the statistical properties as real storms.

To study the downscaling of rainfall, two nested grids of tipping bucket rain gauges were installed in the Tamale experimental watershed during the 2001 rainy season. The larger grid consisted of a 9x9km² area divided into 9 grid-cells of 3x3km². The central grid-cell of the larger grid was sub-divided with a smaller grid of 9 cells of 1x1km². Large variations in rainfall totals for individual storms were measured by the different rain gauges within each grid. The coefficient of variation was on average 0.42 for the large grid and 0.32 for the small grid. Clearly, one can not directly compare results from atmospheric models like MM5, that basically give point results, with that of individual rain gauges. For large storms (>20mm), the coefficient of variation was 0.35 for the large grid and 0.24 for the small grid. These large storms are relatively rare, 18% of total number, but produced 60% of the total rain. Rainfall intensities were high (up to 150 mm/h) and very variable within storms. Intensities within some storms could be divided in a short, intensive convective part and a long tail with low intensities associated with advective rainfall. Statistical properties of the two types of rainfall were different, not only in mean but also in variance and fractal dimension. These detailed measurements over time and space will enable the statistical downscaling from a 9x9km² grid to individual slopes.

Meteorological modeling

The upscaling and downscaling of meteorological variables described above is very important for the proper understanding of the feedback between land surface and atmosphere. Any changes in this feedback will have direct and indirect effects on the regional weather. Our main instrument for the analysis of the impact of these changes and global climate change is the meso-scale meteorological model MM5. Significant progress has been made in the first twenty months of the project in adapting MM5 for use in West Africa. Here, we first present the general set-up and the optimal choice of sub-models that is now used for our daily weather hindcast. We then describe the technical adjustments that were needed to run MM5 for climate simulations from 2030 to 2039. Finally, numerical experiments concerning the effect of changes in land surface properties on regional weather are presented.

MM5 is run using three nested domains, having a horizontal resolution of 81x81 km^2 (61x61gridpoints), 27x27 km^2 (61x61), and 9x9 km^2 (121x67) respectively and 26 vertical layers extending up to 30 mbar. The boundary conditions for the largest domain are provided by global analysis data in the case of daily hindcasting and GCM data such as ECHAM4 for climate simulations. The largest domain provides the boundary conditions for the second domain, and the second domain for the third. The third domain covers the Volta Basin. MM5 includes the Oregon-State-University Land-Surface-Model (*OSU-LSM*) thereby allowing investigation of feedback mechanisms between land use change and precipitation as well as regional climate simulations. The OSU-LSM makes use of vegetation and soil type in calculating infiltration, percolation and evapotranspiration. Inputs are surface-layer exchange coefficients, radiative forcing. Precipitation rate and surface fluxes are fed back to the atmosphere.

MM5 comes with different empirical schemes for microphysics (6), cumulus parameterization (4), and cloud radiation (3). To find the optimal combination among the 72 possible combinations of schemes, a step-wise optimization was performed by comparing rainfall measured at 28 stations with predicted rainfall over the period 15 July 1998 through 14 August 1998. Large differences were found for different schemes. The optimal combination used the cumulus parameterization of Grell, microphysics according to Reisner, and the radiation scheme according to Dudhia with a RMSE of 56 mm. Given the large natural spatial variability, as described above, this result is satisfying.

Since 1 October 2000, MM5 is used for operational hindcasting. Each night, data are automatically retrieved from NCEP (global re-analysis) and WMO sources (observation data), and an operationalized preprocessing chain of MM5 is started. In approximately 6 hours on a double processor SGI Octane 250 MHz, MM5 calculates the weather patterns in the three domains for the past 24 hours. Data for the smallest domain, covering the basin, is then made available on a FTP server to all project partners, especially the hydrologists, remote sensing specialists, agronomists and agricultural economists who use the data as distributed input for their own models. For each of the 8107 grid-points and for each three-hour interval, the values of 20 variables are stored, such as rainfall, air temperature, latent and sensible heat flux. The actual precipitation field is visualized and can be viewed under *http://www.glowa-volta.de/atm/hindcast.htm*. Figure 2 is an example from August 2001.

The main purpose of MM5 is to run climate simulations to investigate how land use change and global climate change affects precipitation. However, MM5 is designed as weather prediction model and had to be adjusted to do long-term simulations. Global climate enters as boundary conditions of a GCM at the largest domain. The GCM used here was ECHAM4 of the Deutsches Klimarechenzentrum for the years 2030 through 2039. A series of practical problems had to be solved before the 4.3 GByte of ECHAM4 data could be used with MM5, such as adjusting calendars (ECHAM4 simulations have 360 days per year), map projections of grid points, and vertical interpolation to pressure levels. First tests with data from recent years show that certain structural phenomena, such as the reduced rainfall along the coast between Accra and Lomé, the so called "Togo gap", are indeed reproduced even though these phenomena are not discernable in the much coarser ECHAM4 data.

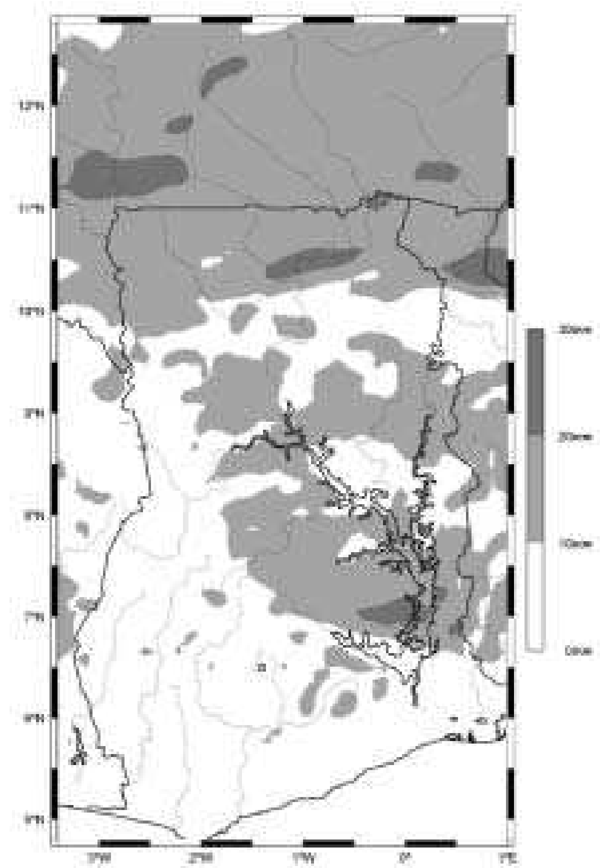

Figure 2: Rainfall (mm) output of MM5 with simplified scale

Most models developed within the GLOWA Volta project will be small enough to run interactively for decision support. Clearly, MM5 climate simulations are too CPU intensive for interactive use. It is, therefore, very important that a set of landuse change scenarios is developed that cover the extremes in terms of climate impact. The climates associated with these scenarios can then again be used interactively. As a first step, we identify areas that have relatively large impacts on regional circulation. This is done through different types of feedback analysis.

First, the effect of changes in initial soil moisture was studied for a one month period. Changes in soil moisture had large, but locally different, effects, showing that land surface properties are indeed of great importance for local weather. Surprisingly, lower initial soil moisture in the Volta Basin resulted in higher rainfall caused by an increase in precipitation efficiency. To better understand which areas are important, evapotranspiration tagging is now used to trace water that evaporates in a certain to the place where it rains down again. Again, results show large spatial variation suggesting that the large effort that goes into the meteorological modeling is necessary in order to be able to understand the feedback between atmosphere, landuse and water use.

Project ID: 07 GWK 01 (Land Use Cluster)
01.05.2000 – 30.04.2003

DATA GATHERING METHODS FOR LAND-USE CHANGE MODELING

W. Agyare, A. Ajayi, B.O. Antwi, T. Bagamsah, T. Berger, A. Braimoh, N. Codjoe, S. Duadze, M. Fosu, G. Menz, S.J. Park, D. Tsegai, F. Vescovi, P.L.G. Vlek, T. Yilma,

Center for Development Research (ZEF), Bonn University, Walter-Flex-Str. 3, 53113 Bonn, Germany.
p.vlek@uni-bonn.de, http://www.glowa-volta.de

Keywords: Land-use change, SVAT model, common sampling frame, hotspot analysis

Abstract:
This research cluster aims to 1) understand the interactions between people and their natural environment to predict land-use change within the Volta Basin, and 2) model the effect of land-use change on surface parameters that directly affect the hydrological cycle. During interdisciplinary discussions, a new methodological framework was created and implemented during field campaigns. Household and community surveys were completed during the year 2001 using a 'common sampling frame (CSF)', in which data sets taken from the Ghana Living Standards Survey (GLSS) and biophysical factors were merged to increase the reliability of survey activities and to generalize the findings to national and basin levels. Intensive field measurements were carried out to characterize the input parameters used in the Soil-Vegetation-Atmosphere-Transfer (SVAT) model in three experimental watersheds. Remote sensing and GIS facilitated coordination between surveys and field experimentation. In addition, an interdisciplinary effort to build a land-cover and soil database was initiated to link research findings at different spatial scales. In order to ensure further interdisciplinary linkages, detailed socio-economic and natural resource aspects of land-use change were investigated at three 'hotspots' within the basin.

Results:
This research cluster involves a wide variety of research disciplines and techniques, including remote sensing, geographical information systems, agricultural economics, landscape ecology, soil science, and hydrology. Harmonizing these different disciplinary viewpoints and techniques was the main methodological challenge. Continuous interdisciplinary discussions created a new methodological framework (Figure 1), which was implemented during the field campaigns of the year 2001. This framework ensures a maximum of overlap not only between socio-economic and biophysical field observations, but also between different observation scales of individual subprojects.

Three integrative research methodologies were developed and applied: a common sampling frame, intensive field experiments, and cross-scale linkages. The main research progress will be described in this section according to these methodologies.

Common sampling frame
Land use change is the outcome of social as well as physical factors and processes. Predictions concerning land use change can only be made if all relevant factors are taken into account. Such interdisciplinary modeling demands a coherent database but building such a database poses methodological problems. For socio-economists, the main unit of observation is the individual household that takes decisions regarding the use of water and land resources.

Institutional analysts, on the other hand, focus on decision-making processes at higher levels of social organization, such as community, region and country. Finally, hydrologists and soil scientists,

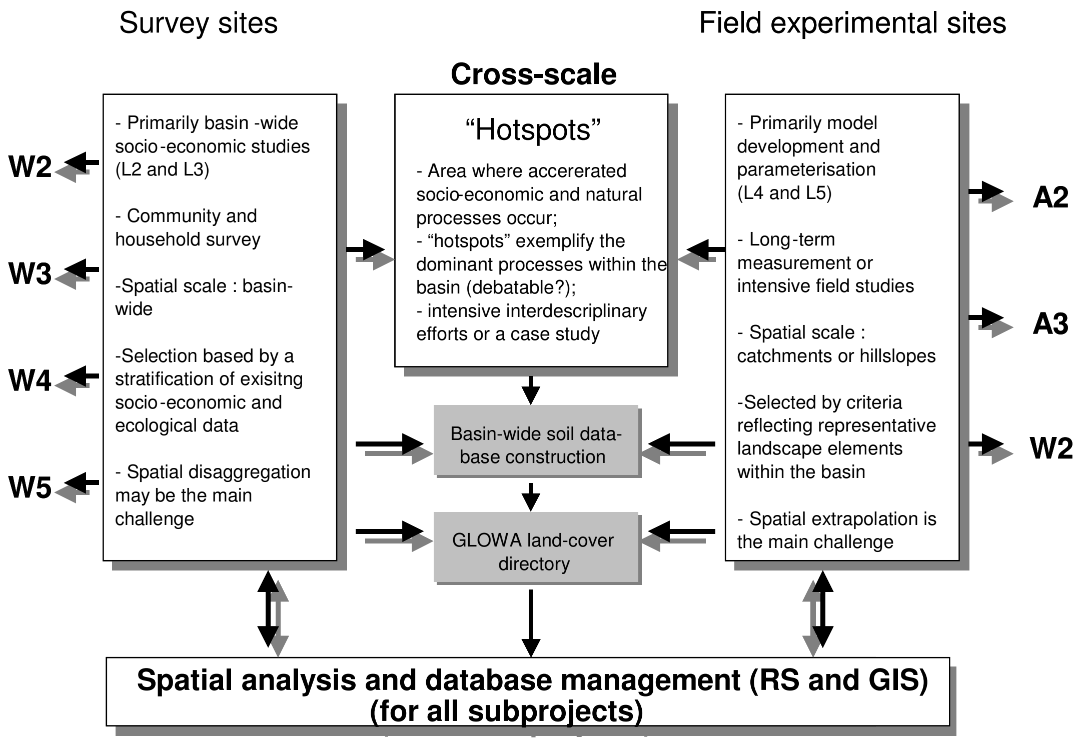

Figure 1: Methodological framework for land-use clusters and linkages with atmosphere and water use clusters

use research units that are related to landscape boundaries rather than social entities. In order to link data across different observational units, a common sampling frame (CSF) was developed that allows generalization of the findings to the basin level through the Ghana Living Standards Survey (GLSS). The GLSS was used as a "map" of the socio-economic landscape, not unlike the way in which satellite data provide a map of the physical landscape.

Representative communities were selected from the Ghana Living Standards Survey as main observation units. The GLSS, which was conducted by Ghana's Statistical Service, provides comprehensive data on various aspects of household economic and social activities, as well as on community characteristics. Of the 6,000 households sampled in the GLSS, 2,240 fall within the Volta Basin. A list of 22 selection variables was constructed that captured socio-economic as well as physical and ecological characteristics within the basin. A principal component analysis and subsequent cluster analysis identified 10 clusters or strata of communities with different characteristics with regard to the selection criteria. Depending on cluster size, one or two communities closest to the cluster centroid were selected as representative communities (Figure 2). The experimental watersheds were added to the sample to ensure overlap. This resulted in a survey list of 20 communities. The various sub-observation units such as sample households, plots and water sources were randomly drawn from each survey community. An interdisciplinary research team conducted the survey activities and field measurements in 2001. In addition, a short standard questionnaire was developed that determines to which cluster a household belongs. This standard questionnaire was used as a "Social Positioning System" in other surveys (see below) to facilitate proper interpolation of the results.

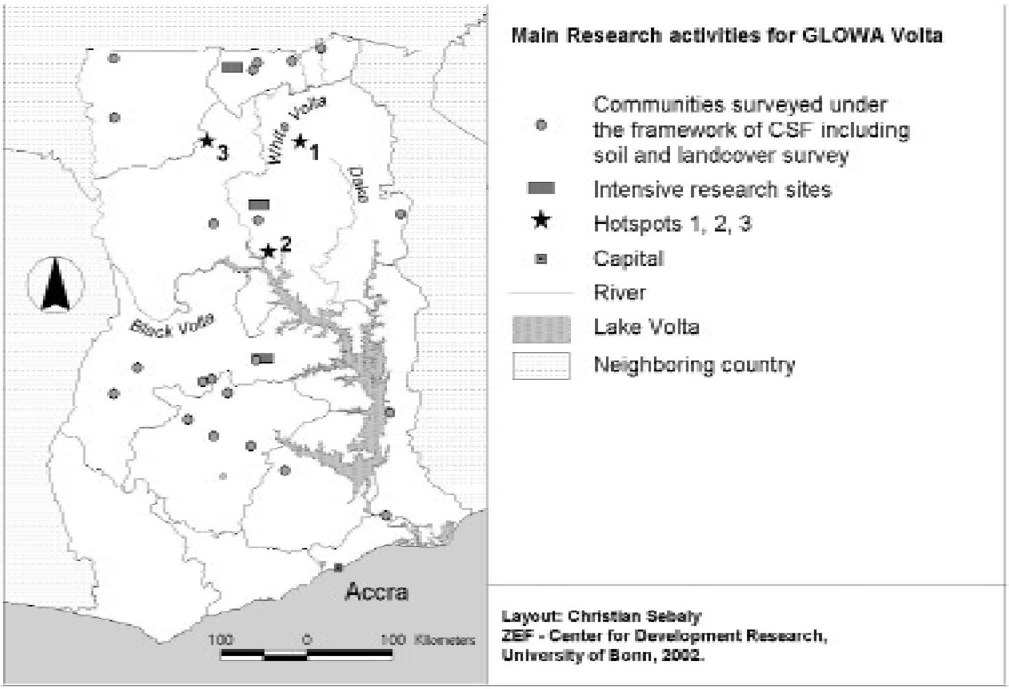

Figure 2: The study sites where main research activities were carried out during the year 2001.

Experimental watersheds

Characterization of the SVAT input parameters for the MM5 meteorological model (see Atmosphere Cluster) requires intensive field sampling and experimentation. Three experimental watersheds were chosen, representing the agroecological zones in the Ghanaian part of the Volta Basin. From North to South: Navrongo, Tamale, and Ejura (Figure 2). All necessary equipment, including weirs, automatic meteorological stations, scintillometers, and surface-runoff plots, was installed and measurements started in April 2001. Many of these research activities are closely linked with individual research activities of subprojects in the Atmosphere and Water Use clusters. This section presents only progress concerning soil and vegetation characterization at the experimental watersheds.

The first phase of the field investigation of spatial variability of soil attributes was completed at the Tamale site. Objectives of this study were to 1) compare different available pedotransfer functions for the prediction of soil-physical properties, and 2) find correlations between individual soil attributes and other, more readily available, variables such as topography and remote sensing signals. The second objective assumes that soil attributes at a given location are the product of various environmental factors that can be modeled and predicted by advanced soil-landscape analysis. Once this analysis is completed, it will greatly accelerate the soil characterization for the whole basin.

To study the partitioning of rainfall over surface runoff and infiltration, sets of runoff plots were installed. Plots of different lengths are used to verify runoff models that explicitly address scale effects, thereby allowing aggregation of point runoff to slope and watershed runoff. Detailed micromorphological characterization and infiltration tests of the plots at the Ejura site reveal that surface crusting is the main cause for enhanced surface runoff. Crusting, in turn, is closely linked with land-use systems. A new terrain characterization algorithm was developed to classify landscapes into different hydrological response zones over the catchment. This algorithm will be tested at the experimental sites, once the on-going measurements for a detailed digital elevation model (DEM) have been completed. This approach will greatly improve our ability to characterize the spatial distribution of surface runoff.

To measure long-term erosion rates under different environmental and land-use conditions, Cs-137 and Pb-210 techniques were applied. During the last two decades, the efficiency and the value of the Cs-137 has been increasingly recognized as a means to estimate spatially distributed mid-term (10-30 years) soil erosion rates. The application of this technique under tropical conditions, however, has been limited, firstly because the amount of radionuclide fallout was low due to the atmospheric circulation and secondly because of the lack of available equipment in the tropics. Two transects at the Ejura site show that the level of Cs-137 is indeed low (2-3Bq/kg with 10% measurement error), but high enough to utilize this technique for the validation of surface runoff and erosion process models.

An initial survey of vegetation characteristics was performed during remote sensing field campaigns and during a bush fire survey during the year 2001. A more intensive biomass measurement campaign in connection with the spatial characterization of the vegetation will be carried out in the middle of 2002. Vegetation characteristics vary over the landscape. The Normalized Difference Vegetation Index (NDVI) generated from remote sensing images shows interesting correlation patterns with topography at the Tamale site. Water movement through the landscape as well as land management by farmers, who grow different crops at different topographical positions, result in a clear spatial organization of the vegetation. Like the soil-landscape analysis, this vegetation-landscape analysis will greatly improve vegetation characterization throughout the basin.

Cross-scale linkage – 'hotspots' and resource database construction

The common sampling frame and experimental watershed approaches differ in their spatial scales and measurement intensity. Remote sensing and GIS are very efficient tools to bridge the different spatial scales of the field investigations. Continuous discussions between those scientists involved in the experimental watersheds and those involved in household and community surveys, facilitated the forging of one spatial information system. As an example, during the cluster analysis of GLSS data, ecological selection variables, such as climate and geology, were included to ensure that different physical environments were accounted for. On the other hand, socio-economists collected soil samples and land-cover information during their household and community survey. All this information was geo-referenced using GPS, and stored in a consistent database structure throughout the project. Social information can thus be linked to physical characteristics. At the same time, our standard questionnaire or Social Positioning System allows the linking of environmental information with the GLSS. Thus, the database provides an informational link between research findings at different spatial scales by different disciplines.

As part of our effort to ensure a tight cross-scale linkage, the GLOWA Volta land-cover and land-use classification was developed and implemented during the year 2001. The classification system is a modification and compilation of the following existing classification systems: 1) Ghana land-cover and land-use classification system; 2) FAO Africover Land Cover Classification (LCCS), and 3) ITC/FAO/WAU Land Use Database (LUDB). The first priority for the GLOWA Volta classification system was consistency with existing Ghanaian and International classification systems, in order to avoid unnecessary loss of information and to secure future collaboration with other research activities. In the new system, land cover and land use are separately considered as a hierarchical and modular system. A standard land-cover-recording chart was developed and used in all surveys.

Construction of the soil database is another effort to ensure cross-scale linkages and interdisciplinary collaboration. Given the objectives of the land-use cluster, characterization of soil quality as a natural potential factor for land-use change and hydrological properties as parameters for the SVAT model is essential. Although a FAO Level 2 soil map is available in Ghana in digital form, detailed soil attribute information required for land-use and SVAT modeling is lacking. During the household survey and other detailed field investigations, basic soil attributes including bulk density, soil pH, organic carbon and soil texture were measured as key soil attributes.

As it is not possible to study land-use change for the whole Volta Basin at a fine spatial resolution, there is a need to select key areas to do detailed research. We use the so-called 'hotspot' concept to select sites and link local to regional land-use change. Hotspots are defined as areas where accelerated socio-economic and natural processes occur. Due to their rapid changes, investigations at hotspots increase the chances of finding land-use change drivers and constraints within a relatively short time period. At three hotspots, field surveys were conducted in 2001. The topics of these studies are 1) population growth and migration in Kassena-Nankana district; 2) seasonal migration and land-use changes in Wuripe village, northern Ghana; and 3) the influence of bushfires on vegetation characteristics and nutrient cycles (see Figure 2). They all involved both socio-economic (questionnaire and interview) and natural resource (soil and vegetation sampling) aspects of land-use change.

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01.05.2000 – 30.04.2003

OPTIMIZING WATER USE FOR FUTURE SUPPLY AND DEMAND

B. Amisigo, T. Berger, M. Iskandarani, W. Laube, J. Liebe, O. Müller, P. Obeng-Asiedu, Y. Osei-Asare, C. Ringler, N. van de Giesen, A. van Edig, C. van der Schaaf

Center for Development Research (ZEF), Bonn University, Walter-Flex-Str. 3, 53113 Bonn, Germany.
t.berger@uni-bonn.de, http://www.glowa-volta.de

Keywords: transboundary water management, inter-sectoral water allocation, water institutions, household water security, water-related health aspects

Abstract:
The water cluster examines changes in water supply and demand as well as the hydrological and socio-economic trade-offs in water allocation. Research activities focused on analyzing secondary data, collecting primary data on household and community level, as well as conducting first analyses of policy scenarios with the help of an integrated economic-hydrologic optimization model. Based on ten-year average data and an institutional analysis of the water sector, we developed alternative water management scenarios and assessed them in first runs of the economic-hydrologic optimization model. The initial model results suggest that the effect of increased irrigation development is small compared to rainfall and runoff variability in the Volta basin. A series of models runs simulates the effects of different scenarios of electricity trade and power generation expansion. As far as the domestic use of water on household and community level is concerned, secondary data analysis showed that only around forty percent of rural households and about fifty percent of urban households use improved water sources for their drinking water needs. Further efforts to expanding the provision of improved water sources are, however, only one part of the solution. The analysis indicated that a household's choice between improved and traditional drinking water sources not only depends on the household's income level and distance to the source but is also determined by other factors such as education and preferences or taste. Mapping of water-related diseases, moreover, underlines the importance of health effects through water use.

Results:
Research in the five subprojects of the water use cluster has yielded the following achievements, which in some cases are quantitative and qualitative results and in other cases intermediate "products" for on-going research activities.

Node-link network
The node-link network, jointly developed in subprojects W1 and W2, represents the spatial structure of the surface water resources system in the Volta Basin. It consists of source nodes (rivers and reservoirs) and demand nodes (irrigated cropping areas, industrial and household consumption, hydropower). Based on time-series data for rainfall and run-off, a total of thirteen nodes has been identified in the Volta Basin, divided over different agro-ecological zones (Figure 1). Five nodes are in the Sudan savanna, six in the Guinea savanna, and two in the Coastal savanna. Crop-water demands and irrigation efficiencies were calculated for these agro-ecological zones. For each node, a hydrologic water balance was established to inform the subsequent water optimization model.

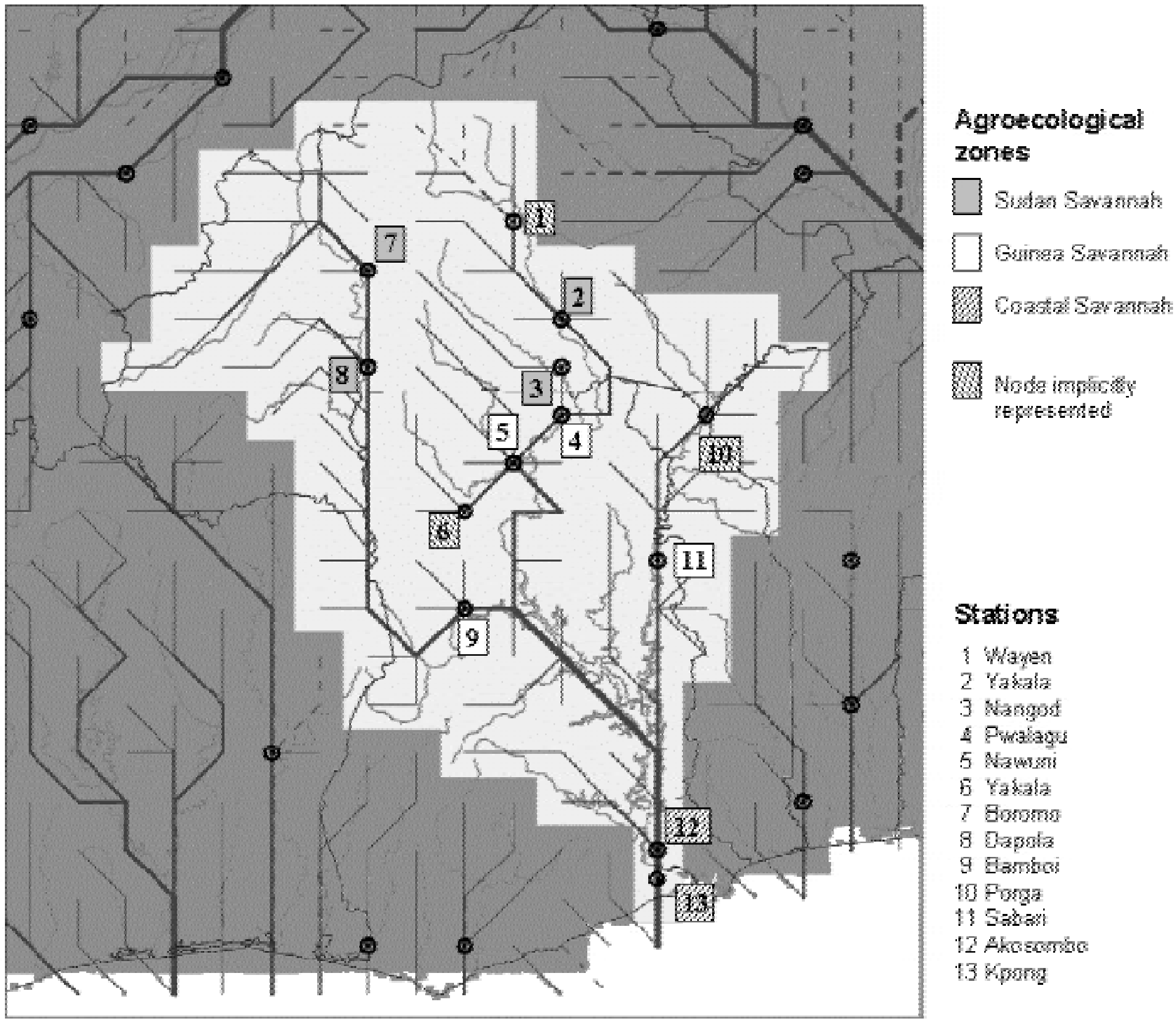

Figure 1: Node-link network of the Volta river basin

Institutional analysis

Several rounds of interviews with regional experts from the water sector revealed major policy reforms have deeply affected the institutional set-up since the end of the nineties. Basically four types of institutions were defined: national, regional, district, and local. Many national institutions tend to delegate responsibility to the regional and district level, who in turn have to cooperate with the local level. First results of the analysis of the local institutions (see below) and the national institutions indicate that many implementation problems occur at the district level, as these institutions are neither sufficiently financed nor trained for the tasks they have to fulfill in water management. The interviews with experts at the national level as well as recent literature underlined high priority for the electric power sector in Ghana. It is likely that this sector will develop various projects (hydropower, thermal plants, West African Gas Pipeline) in order to reduce the regular power shortages regularly in the country. To supply the population with sufficient electricity is at the top of the political agenda.

Decision-makers in various Ghanaian institutions agreed that competing water use between hydropower and irrigated agriculture should be avoided. If irrigated agriculture is to be expanded, this should be in places where there is no competition between agricultural and hydropower use as the area below the Akosombo dam. On the other hand, riparian countries also aim at expanding irrigated agriculture and developing hydropower. Burkina Faso for example is planning a hydropower dam for the supply of Ouagadougou. Togo and Ghana had an exchange agreement on electricity. It is the basis for importing energy from Ghana in the rainy season and exporting it to Togo in the dry season. Togo furthermore exported energy to

Ghana in the peak time of the daily power consumption. Togo has recently developed its own thermal plants and does no longer depend on Ghana for power production. Close cooperation is thus needed for the riparian countries in the Volta basin to make an optimal use of the available water resources.

Development of scenarios for water-optimization model

One major result of the institutional analysis was the development of scenarios for the integrated water-optimization model. Institutions, formal as well as informal, were integrated as constraints in the economic model. Policy scenarios were based on official Ghanaian development planning for the next two decades that entail major changes for water use. The scenarios were grouped according to the principal water-use sectors agriculture, households, industries, and hydropower. The scenarios also include institutional and socio-economic processes such as international cooperation and increased demand for energy and food:

- The first scenario prescribes basic supplies of water and electricity for the Ghanaian population in 2020. By then, every citizen will have access to potable water and electricity.
- The second scenario relates to the expansion of irrigated agriculture. It assumes that the area under cultivation will either be increased 26-fold by 2020, as suggested in policy documents, or that all presently planned irrigation projects will be established.
- The third scenario includes changes in hydropower production in Ghana. In this scenario, the Bui hydropower project is realized, and energy imports and exports are changed.
- The fourth scenario sets increased hydropower and agricultural development for Burkina Faso. If Burkina Faso starts to develop either irrigation or hydropower projects this may have impacts on the availability of water to Ghana.
- The fifth scenario shows the effect of electricity trade and capacity expansion in Ghana and the neighboring countries.

Preliminary assessment of policy scenarios

The scenarios outlined above are analyzed in subproject W2 with an integrated mathematical programming model that combines the hydrologic node-link network, the water-production functions for agriculture and hydropower, and the market and policy environment. Demand functions for agricultural products are included. Institutional constraints are reflected in water quotas allocated to different water sectors. In the first simulation runs, the quantities for domestic demand, energy, as well as energy imports and exports were fixed. The model was then used to determine the least-cost energy generation in Ghana while allocating water across different demand nodes based on its economic value. Although the simulations need further validation, some results will be presented here in order to demonstrate the type of information the model generates.

The model scenarios based on ten-year averages for runoff and rainfall show the difficulty of producing enough hydropower. Average energy demands in Ghana can only be met by over-exploiting the water resources entering Lake Volta in the order of ten percent of normal long-term storage levels. All other things being equal, hydropower generation would have to be reduced if Lake Volta were to be operated in a sustainable manner. Another series of simulations analyzes the effects of different scenarios of electricity trade and capacity expansion in Ghana and the neighboring countries. Based on model data for the West Africa Power Pool (WAPP), developed in an USAID funded research project at Purdue University, we test different investment scenarios such as new hydropower and combined cycle generation in Ghana. Irrigation development upstream in Burkina Faso or Northern Ghana does have an effect on the reservoir level but not as dramatic as public debates in the Ghanaian media might suggest. Rather, the model runs support the general hypothesis that climate impacts on the hydrologic cycle are decisive for local water availability and thus economic demand patterns. Since the model employs a spatial representation of available water resources in the Volta basin, the spatially explicit predictions from the Atmosphere Cluster will be linked directly to find future optimal water distributions. Preliminary model runs only employed secondary data that will be gradually substituted by primary data such as already collected in subprojects W4 and W5. The water allocation model will be integrated with the multiple-agent land use models of subprojects L2 and L3. As outlined in Berger and Ringler (2002), a multi-level multiple-agent framework promises to capture more fully the temporal and spatial scales of interactions between people and their natural environment; to address interrelated water management and land use decisions; and to include policy responses by farmers and other resource users.

Household water security

The basis of the economic and institutional analysis on local level is a comprehensive community and household survey that was designed and implemented in 2001 (see also Land Use Cluster). The survey design applies an integrated sampling approach, which facilitates interdisciplinary research by linking biophysical and socio-economic field observations. *A priory* analysis of the Ghana Living Standards Survey (GLSS) was undertaken to gain first insights into socio-economic conditions and water-use patterns in the basin. Several hypotheses on the determinants and likely consequences of water insecurity could be tested. We compared patterns by means of maps and graphs and conducted statistical analyses on households' use of alternative water sources, water expenditures, the incidence of water-borne diseases, and potential links to migration. The results of the statistical data analysis showed that, although substantial success has been made by recent programs in providing communities with access to improved water sources, the actual use of such sources still varies geographically and between households. Within the Volta Basin, around 41% of rural households and about 51% of urban households use improved water sources - such as boreholes or piped water - for their drinking water needs. In the rural areas, about 42% of the households still rely on traditional surface-water sources, such as rivers, lakes, springs or ponds. Rainwater collection does not seem to play a role in the drinking water supply within the basin.

Figure 2 shows the incidence of improved water usage in the Ghanaian part of the Volta Basin based on the GLSS survey sites. It seems that sufficient provision of improved water sources is only one part of the solution. Our results show that household income is an important determinant in preferring improved water sources over traditional water sources. Moreover, education programs may help to increase the use of the improved sources, particularly in communities where until recently no wells with pumps existed, because these communities are not used to the taste of pumped water and are not familiar with the technology. In our analysis of household water expenditures, we find that even when indirect costs are included, the average share of income spent on water lies within the range of 3-5% as recommended by the World Bank. We further examined the consequences of improved water access on migration patterns. Our results indicate that water access and availability have a significant impact on migration.

Water-related health aspects

Closely related to water availability, access and usage is people's health. According to statistical analysis of GLSS data, the major health problems of communities in the Volta basin are malaria, measles, hernia and river blindness. Of these diseases, malaria and river blindness are directly related to water. The incidence of malaria and river blindness in the sample is about 88 percent and 24 percent of the households, respectively. This makes malaria the most important water-related disease in the basin. Data analysis on malaria transmission intensity in the Nouna District in Burkina Faso points to *Anopheles gambiae s. l.* and *Anopheles funestus* as the principal vectors throughout the year, with high transmission intensities (sporozoite rates 5-15%) documented over the main transmission season (June until December), but very low transmission intensity (sporozoite rates <1%) during the dry and hot season (February until May). There are considerable variations in malaria transmission intensity by village and season.

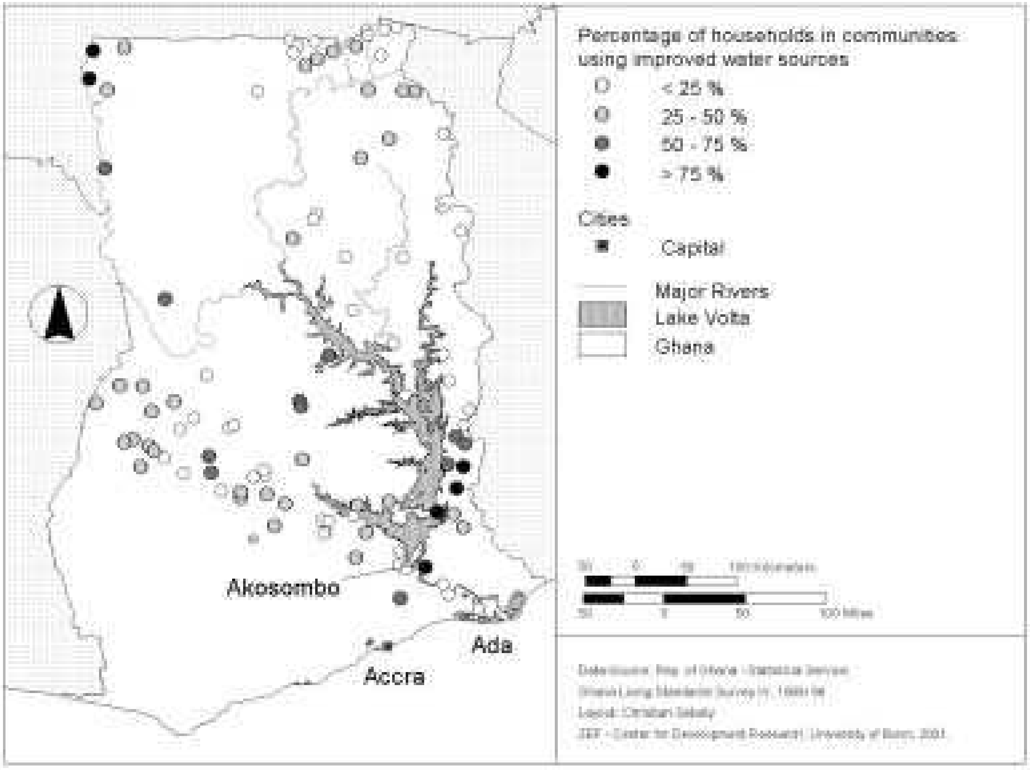

Figure 2: Incidence of improved water usage in the Ghanaian part of the Volta Basin

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Glowa Coordinators

Glowa ELBE

Dr. Alfred Becker
Potsdam-Institut für Klimafolgenforschung
Phone: +49 (0) 331 288 25 41
Fax: +49 (0) 331 288 26 00
E-mail: becker@pik-potsdam.de

Glowa DANUBE

Prof. Dr. Wolfram Mauser
Institute for Geography, Dept. of
Geography and Remote Sensing
University of Munich
Phone: +49 (0) 89 2180 66 80
Fax: +49 (0) 89 2180 66 75
E-mail: w.mauser@iggf.geo.uni-muenchen.de

Glowa IMPETUS

Prof. Dr. P. Speth
Institute for Geophysics and
Meteorology
University of Cologne
Phone: +49 (0) 221 470 36 90
Fax: +49 (0) 221 470 51 61
E-mail: speth@meteo.uni-koeln.de

Glowa VOLTA

Prof. Dr. P. Vlek
Center for Development Research (ZEF)
University of Bonn
Phone: +49 (0) 228 73 17 20
Fax: + 49 (0) 228 73 18 89
E-mail: p.vlek@uni-bonn.de

Contact GLOWA Programme

Dr. Manfred Gast
GSF-Projektträger UKF
Kühbachstr. 11
81543 München
Phone: +49 (0) 89 65 10 88 51
Fax: + 49 (0) 89 65 10 88 54
E-mail: manfred.gast@gsf.de