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Abbreviations

AMMA	African Monsoon Multidisciplinary Analysis
BIOTA	Biodiversity Monitoring Transect Analysis
BON	Biophysical Observation Network
CA	Cluster Analysis
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CSIR-WRI	Council for Scientific and Industrial research – Water Research Institute
DMSP	Defense Meteorological Satellites Program
DSS	Decision Support System
FAO	Food and Agriculture Organization
GAMS	General Algebraic Modeling System
GIS	Geographic Information System
GVP	GLOWA Volta Project
GVDSS	GLOWA Volta Decision Support System
GV-LUDAS	GLOWA Volta Land Use Dynamics Simulator
IFPRI	International Food Policy Research Institute
INERA	Institut de l´Environment et de Recherche Agricoles
IWMI	International Water Management Institute
KACE	Kofi Annan Center for Excellence in Communications Technology
LAI	Leaf Area Index
LC	Land Cover
LCC	Land Cover Change
LCCS	Land Cover Classification System
LUDAS	Land Use Dynamics Simulator
MATA	Multi Level Analysis Tool for Agriculture
MM5	Meso-scale Meteorology Model 5
M^3 WATER	Multi-country, Multi-sector, Multi-use (M^3) Water Allocation Technology for Efficient Management of Resources
MODIS	MODerate resolution Imaging Spectroradiometer
PCA	Principal Component Analysis
SWAT	Soil and Water Assessment Tool
TWM	Transboundary Water Management
UER	Upper East Region (Ghana)
UNU	United Nations University
VBA	Volta Basin Authority
VRA	Volta River Authority
WAPP	West African Power Pool
WaSiM	Water Flow and Balance Simulation Model
ZEF	Zentrum für Entwicklungsforschung

Introduction

The GLOWA Volta project is in its third and last phase, which is dedicated to data integration, basin-wide and country-specific modeling, the implementation and transfer of Decision Support Resources, the development of practical tools for decision-makers and the close cooperation and capacity building of stakeholders in the Volta Basin.

The event that most defined 2008 was the International GLOWA Conference, which was held in Ouagadougou, Burkina Faso, in August. The conference was organized under the leadership of K. **Vielhauer** and C. **Arntz** at the Center for Development Research in Bonn, and supported by D. **Schmengler** and A. **Brunner** in Burkina Faso, and the ZEF public relations office (A. **van der Veen**). The GLOWA Conference received international media coverage.

One of the greatest challenges for the GVP was to integrate the preparation for the GLOWA Conference into the initial project plan, while making up for previously documented delays with model development, and continuing to promote the transfer of the tools to the Volta Basin.

The concept of multi-level GLOWA Volta Decision Support was consolidated (Figure 1), which provides different sets of decision support at the scale appropriate to address the problems. A number of key models have been completed or have made significant progress. Our hydrological model, the Volta Basin Water Allocation System (VB-WAS) was brought to maturity and has already found its practical application in assessing the impact of Bui dam, which is currently under construction in Ghana, and on water storage in Lake Volta, which was presented in conjunction with the GTZ organized “Dam Dialogue”. Our new economists N. **Perez** and A. **Bhaduri**, who joined the project in late 2007 and early 2008 respectively, joined the interdisciplinary research group together with hydrologists and computer scientists to develop the complex hydro-economic optimization model M³WATER. This model can be used to assess the effect of different policies concerning water use on the overall social benefit, also with respect to climate change.

Significant progress was also made with the GLOWA Volta Geodatabase and Geoportal. The Geodatabase is now operational and is stocked with data. The Geoportal, a multifunctional, web-based interface for the Geodatabase, was completed and can be used to search and visualize geospatial data.

Additional models, such as the model for the prediction of the onset of the rainy season (ORS), and the regional models LUDAS and LAMPT were also completed.

Besides model development, the presentation of project goals and results were promoted together with a set of PR measures, such as new project flyers and information sheets. Another important measure to improve information flow, and to facilitate the transfer of tools and results, is the newly developed project homepage, which replaced an outdated homepage about mid-year. The new webpage now reflects the project structure of the third phase, and provides up-to-date information on the project’s components and results. A major innovation is the inclusion of the GVP Geoportal.

In conjunction with the GLOWA Conference, the Center for Development Research financed a journalist trip to the Upper East Region of Ghana, one of the major GLOWA Volta research areas. Journalists from ARD, DIE ZEIT, Süddeutsche Zeitung, Deutsche Welle, and Deutschlandfunk were introduced to the area and its problems in the face of climate change. This resulted in a variety of publications, both as press articles, and as radio broadcasts, leading to the best media coverage of the Project since its inception.

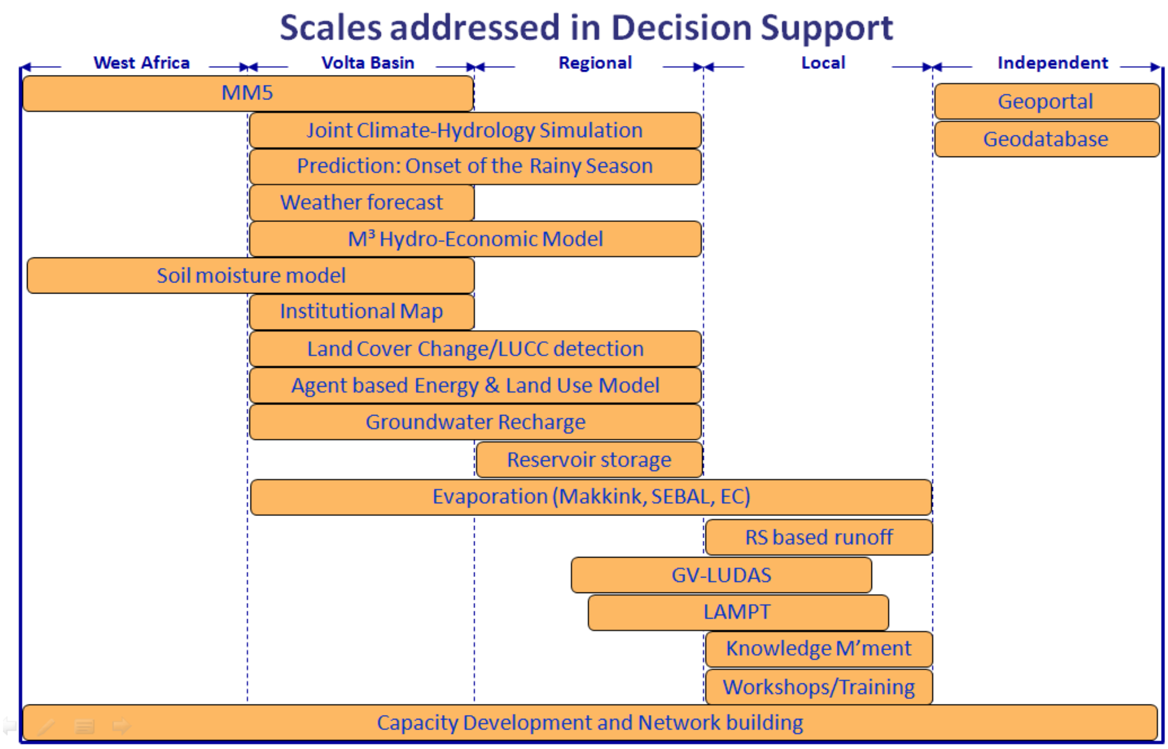

Figure 1: GLOWA Volta Decision Support Tools

Source: Liebe 2008

To facilitate the transfer of GLOWA Volta Products into the Basin, GVP engaged in an intensive outreach program. Despite the GLOWA Conference, six trainings and workshops[1] were delivered in Burkina Faso and Ghana, involving a variety of stakeholders and technical personnel interested in our tools. These workshops prove to be very well received, and the workshop series will be continued in 2009.

Another five GLOWA Volta students graduated in 2008. We congratulate M. **Mdemu**, S. **Wagner**, E. **Obuobie**, and J. **Friesen** for their excellent PhD research, and J. **Laubach** to his excellent M.Sc. (Diplom).

After C. **Rodgers** accepted a position in Washington, D.C. and left the project at the end of 2007, J. **Liebe** assumed the position of the project coordinator in January 2008. With the two economists, N. **Perez** and A. **Bhaduri**, the economic component of GVP was significantly revived and the development of the hydro-economic optimization model gained momentum. A. **Mittelstaedt** was hired to develop the new web page.

Problems persisted in the completion of some of the tools and models, especially the hydro-economic optimization tool M³WATER, which is technically highly complex, and in

[1] For an overview, see http://www.glowa-volta.de/results_trainings.html

honing the GVP Geodatabase and Geoportal. The grounds for solving the remaining problems in 2009 have been laid out in the form of intense, interdisciplinary group work, which is time consuming, but effective in transdisciplinary problem solving. Such group meetings will be continued in 2009 to bring the models and tools to maturity, which allows their final transfer to the Volta Basin.

Another event of relevance relates to our project partner, the Volta Basin Authority (VBA). In November 2008, Ghana and Togo agreed to ratify the VBA as the third and fourth riparian countries. This move helps defines the point at which the VBA becomes operational. Through this progress in the ratification process the development of the VBA received much momentum, and undergirds the suitability of the VBA as one of the major recipient of GLOWA Volta products. The Geodatabase and the Geoportal are scheduled to be transferred to the VBA in 2009, along with training measures. To further promote our tools in the Volta Basin, a range of trainings and workshops will be continued in Burkina Faso and Ghana.

Completed work from Phase II Clusters and ongoing projects which contribute to several clusters

Due to changes in the project structure at the beginning of the third project phase, some research activities cannot directly be summarized under the following project clusters. A number of PhD projects, which started in 2002-2003, were completed in 2008. This section also incorporates ongoing projects which contribute to several clusters.

Methodology and results:

Research activities of A. **Brunner** focused mainly on the completion of the PhD research, entitled ”Modeling soil erosion and reservoir sedimentation at hillslope and reservoir scale in Burkina Faso”. Whereas on-site effects of soil erosion have been measured, analyzed and interpreted at hillslope scale by catenary soil sampling, ^{137}Cs-method and erosion simulations by the Water Erosion Prediction Project (WEPP)- model (see annual report 2007), off-site effects such as the siltation of small reservoirs have been evaluated at reservoir scale. The construction of small dams is a common practice for dealing with erratic and unevenly distributed rainfall in semi-arid environments. In Burkina Faso, more than 850 dams have been constructed. Dams have the function to store rainfall and runoff water from the catchments and serve as water storages for domestic use, agriculture and livestock. At the same time, they present major sink areas for sediments from upstream. Incoming and accumulated soil particles can lead to severe changes in reservoir morphology, which influence in return water storage capacity and water use potential. Small reservoirs are especially severely affected by these storage losses. As their maximum water depth is often only a few meters, evaporation losses are comparatively high and an increase in accumulated sediment at the bottom of the reservoir leads to a relatively high reduction in storage volume. Therefore, the specific objectives of this study were i) to monitor changes in reservoir morphology by comparing the initial topography with current bathymetric maps ii) to measure the thickness of accumulated sediments by sediment coring and iii) to calculate annual siltation rates and sediment budgets to estimate the “half-life” of the reservoir.

The siltation rates of three small reservoirs in southwestern Burkina Faso were calculated by quantifying the sediment input from the surrounding catchment area.

Therefore, changes in reservoir morphology have been compared at two different time periods, first at the time of the construction of the dam, and second at the time of the actual bathymetric survey. The initial topographical map of the reservoir and the corresponding geo-technical report provided the required information about area-volume curve, potential water storage capacity, dam, spillway and overflow parameters and additional construction details, such as degree of surface soil disturbed or sediments removed. Based on the initial elevation points of a topographical map (resolution 1:1,000) a DEM was generated in Surfer (Golden Software, version 8.0). The actual morphometry of the reservoirs was measured either directly by a topographical survey using a tachymeter (Leica, type Wild NK-1 non-automatic tilting level) (Figure 2) or indirectly by a bathymetric survey using a water-depth-sounder with a mapping GPS unit (Lowrance, LMS-480M) attached to an inflatable boat. Furthermore, undisturbed sediment cores of up to 1 m length were taken by a Beeker sampler from the bottom of the reservoirs in order to verify and validate bathymetric results. Stratification techniques, such as the detection of vertical changes in soil texture, soil structure and/or chemical composition (e.g. 137Cs), were used to identify accumulated versus in-situ sediment. By knowing the thickness, bulk density and initial unit weight of the accumulated sediment, total sediment yield and annual siltation rates of the reservoirs were determined.

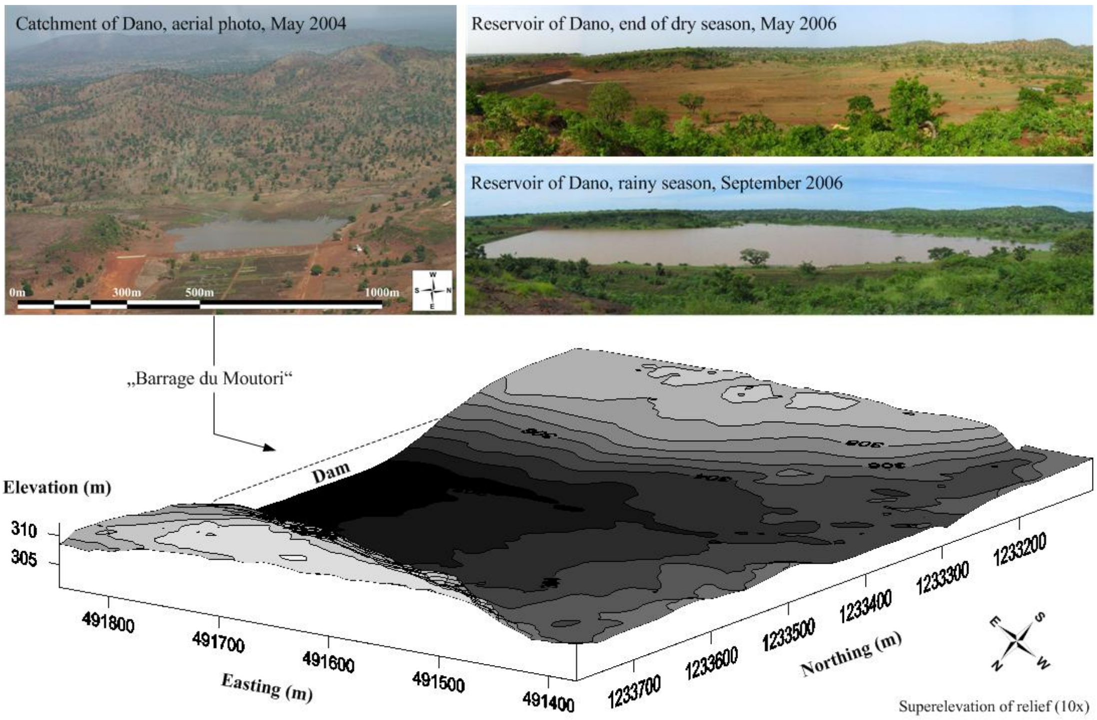

Figure 2: Morphology of the small reservoir in Dano, southwestern Burkina Faso

Source: Brunner 2008

Results indicate an average annual sediment gain of approximately 2-3 cm thickness, which can be interpreted as already critical in relation to the shallow depth of 1.5 m to max. 3 m at the peak of the rainy season. In regard to the low total water volume of 0.4 to 0.8 Mm³, this implies that about 2 % of the initial water storage is lost each year due to reservoir siltation. According to these losses, the half life of the reservoirs, which expresses the time required to infill half the original capacity, will be reached in approximately 30-40 years. It is obvious, that the continuous siltation and reduction in water storage capacity will severely affect water availability and its efficient use for irrigation agriculture in the dry season. As it is technically difficult, cost-intensive and not feasible for most sites in Burkina Faso to recover the capacity of these small reservoirs by dredging or hydraulic flushing, control measures and prevention methods are becoming increasingly important. The use of soil and water conservation methods in farmers' fields (e.g., stone lines, vegetation barriers, plowing along contour lines) and the construction of intermediate check dams at most affected runoff and sediment flow pathways, could be one option to counteract soil loss at its initial source of origin.

T. **Frazier**'s research establishes a means to project energy demand for Ghana's most significant area of consumption, the Greater Accra Region (Figure 3), based on decision paths related to energy and land use. He conducted field research in Ghana and returned to Germany in spring 2008. His work uses an agent-based, multinomial logit approach for making demand projections based on business-as-usual, weak sustainability, and strong sustainability scenarios in terms of high, medium and low economic and population growth rates. Transition models, relocation models, location choice models, and land value and energy demand models rely on robust parcel, building, household and economic data to simulate urban and regional development throughout Greater Accra. The result is a comprehensive simulation of Greater Accra's urban and regional development that is used to forecast the aforementioned scenarios and their associated net present value over the next 30 years. Comparing the net present value of the potential land and energy use policy cadres serves as the justification for the resultant Comprehensive Energy Use Plan for Greater Accra, Ghana.

Figure 3: Population density in central Accra

Source: Frazier 2008

In Ghana, increasing agricultural productivity is seen as an essential component of most development programs. This increase in productivity can lead to increased transport of nutrients in surface runoff into aquatic systems. The PhD project of A. **Mensah** was an integrated assessment of the implications of increased land use activities on in-stream nutrients and impacts on the quality of water for domestic use and on aquatic ecosystem health. To guide the evaluation of the land-water interlinkage, the conceptual structure defined by the DPCER (Driving force – Pressure – Chemical state – Ecological state – Response) framework was used, an adapted version of the traditional DPSIR (Driving force – Pressure – State – Impact – Response) model. Driving forces refer to the specific land use activities that lead to the input of material (nutrients, sediments, toxins) (defined as pressures) to change the chemical state of the environment (i.e., the physicochemical characteristics of the water body) and result in changes to the ecological state (ecosystem modifications such as changes in biota), with responses as societal measures to improve the state of the water body.

The study compared three small upland sub-catchments in the same geo-morphologic Ofin Basin, located in the Ahafo-Ano South District of the Ashanti Region. Based on the percentage cover of natural land to agricultural land, the catchments were categorized as low (Nyamebekyere), medium (Dunyankwanta), and high (Attakrom) land use intensities. With simple mathematical tools and selected indicators to represent the components of the framework, the performance of each link was evaluated. The framework assessed how specific indicators perform in each catchment, and then compared the behavior between catchments to evaluate interlinkages as a function of increasing land use intensity.

Despite overall minimal fertilizer use in Ghana, there were significant differences between the sub-catchments regarding the proportion of farmers who applied fertilizers. Attakrom showed the highest numbers of farmers (20.5%) as compared to Dunyankwanta (12.3%) and Nyamebekyere (0.0%), with applications mainly to cash crops such as cocoa and maize. Simple logistic regression explained that fertilizer use was considerably influenced by the farmer's access to services such as farm loans and agricultural extension services, in addition to property rights and residential status. The Beale's Ratio method, used to calculate the total annual load (kg yr-1) and yield (kg ha-1) for major nutrients (Ca, K, Mg, Na, NO3-N, NH4-N, and PO4-P), showed that the highest nutrient export was from Dunyankwanta at a relative magnitude of up to 3-fold the values of the other two catchments. The annual water yield was highest in Dunyankwanta (79.91 mm yr-1) as compared to Nyamebekyere (41.33 mm yr-1) and Attakrom (22.87 mm yr-1). Total annual water yield was the main determinant of the total nutrient loads/yields, and ranged between 2.3% and 6.2% of the total annual precipitation. Forty-eight hour grab water samples confirmed that in-stream nutrient concentrations increased with increasing land use intensity, with significant differences between catchments for the major cations (Ca, Mg, K and Na). Median values for all nutrients were in the optimal range of the Ghana Target Water Quality Range (TWQR) for domestic use and for aquatic ecosystem health. The distribution of macroinvertebrate taxa as a function of stream chemistry also showed significant differences in the ecological states of the upland catchment streams.

The DPCER framework with a comparative catchment component was an effective methodology for describing changes as land use intensities. Water yield is important in estimating total nutrient export, and the inclusion of a hydrological component in the DPCER framework is proposed - to form a DHPCER model (Driving force – Hydrology – Pressure – Chemical state – Ecological state – Response). The significant differences observed in each component of the framework strongly suggest anthropogenic influence. With Ghana's objectives for increased agricultural productivity, the results of this study demonstrate the need for incorporating integrated water resource management into development agendas.

The research of M. **Adimabuno Awo** for her PhD thesis "Actors Interest and Collective Action, the Difficulties of Tomato Marketing in Northern Ghana" commenced on 1/01/08, focusing on Ghana and Burkina Faso. Data collection was undertaken from 1/01/08 to 30/06/08 in Kasena Nankana District (KND) in the Upper East Region of Ghana. The focus groups were tomato farmers in three communities (Doba Mirigu and Kandiga) in the KND, tomato traders from the southern parts of the country and intermediaries. The KND gate keepers, political figures as well as staff of government stakeholder institutions such as the Ministry of Food and Agriculture (MoFA), Ministry of Trade and Industry (MoTI) Custom Excise and Preventive service (CEPs) were also interviewed.

Both field surveys and interviews with questionnaires were used to collect data. Field trips were also undertaken to two big markets in the country Makola in Accra and to the Kumasi Central market in Kumasi. A trip was also made to tomato producing communities and the tomato market in Burkina Faso. Since her return from the field, Ms. **Adimabuno Awo** has presented a field report, and since then engaged in data analysis, review of relevant literature on her topic and the writing of the research paper.

The conclusion will be made later. Currently, the data and the structure of the paper is still being discussed with supervisors. The reason for this is to have enough time to analyze the many factors that need to be considered for objective conclusions.

The PhD project of B. **Fosu-Mensah** "Modeling maize production and the potential impact of climate variability on yield in sub-humid region of Ghana using APSIM" has the following objectives: (a) quantify phosphorus and nitrogen interactions on maize yield using field experiment; (b) parameterize and evaluate the APSIM cropping simulation model for the study area; (c) assess the impact of climate variability on maize production in the region using APSIM.

The experiment was located at three different sites in Ejura, based on differences in soil fertility level and soil types. The sites were about 8 kilometers apart. Two sites were for model evaluation and one site for model calibration.

Land preparation was done by spraying Chemosate at 3 l/ha initially to kill the weeds. Soil sampling was carried out by digging two profile pits at each site and soil samples taken at different depths as; 0-15, 15-30, 30-45, 45-60, 60-75, 75-90, 90-100 cm. These samples were oven-dried and sent to the laboratory for analysis for total nitrogen (N), available phosphorus (P), exchangeable potassium, (K), soil organic matter, soil pH, cation exchangeable capacity (CEC), and particle analysis which showed variability in soil types in the region. Plowing and harrowing were carried out using tractor-mounted disc plough and disc harrow. At the time of planting, initial soil moisture, nitrate and ammonia content as well as bulk density were determined at each depth of the soil profile on the day of planting. Thirteen treatments with two varieties were used. Data on plant biomass accumulation were taken at two weeks intervals when plants were one month old. Soil moisture and leaf area index were also taken at one week and two weeks intervals. Data on date of flag leaf, date of tassel, date of silking etc. were also taken.

Genetic coefficients of the two cultivars will be generated using the cultivar file of the Agricultural Production System sIMulator (APSIM) model and some of the data from the field. The initial soil conditions will be used to generate dry lower and upper limits for the model. Model calibration will be made and simulation for the two varieties using weather data conducted. The model will be evaluated by comparing the simulated result and observed data. Historical weather data will be used to generate future climate data to simulate a 30 year impact of climate variability on maize yield in the region. APSIM will also be used in simulating a 30 year yield of maize using different scenarios of nutrient management. The field data collected so far suggests that the application of phosphorus has a significant influence on nitrogen up-take by the plant and hence an increase in yield.

For the assessment of human-induced land degradation in the Volta Basin from 1982-2003 Q. B. **Le**, L. **Desta** and P. L. G. **Vlek** conducted a step-wise analysis using a series of databases to identify the extent of land under anthropogenic threats. By integrating a time-series of NDVI (Normalized Difference Vegetation Index) and rainfall from 1982 to 2002, the researchers delineated the geographic extents of zones with significant biomass decline or improvement in the Volta basin. To distinguish human-induced biomass trends from climate-driven vegetation dynamics, we excluded those areas that had shown a strong biomass response to inter-annual rainfall variation. Pixels with NDVI changes in accordance with rainfall (positive correlation) were considered due to climate change or variation. Pixels not affected by rainfall (no, or negative correlation) are those where green biomass change could be interpreted to reflect areas with strictly human induced land degradation. Spatial data of soil constraints, land use/cover and population density within the study period were used to interpret possible underlying factors of land productivity decline. The results of the study show that about 31 thousand km^2 (8% of the basin land mass), which is the living space of over 1.3 million people, was land that is losing its ability to produce green biomass due to human actions. The degradation areas for the various land cover types are 12.2 thousands km^2 for woodland, 8.3 thousands km^2 for agriculture, 7.3 thousands km^2 for shrubland, and 1.6 thousands km^2 for evergreen forest. The relatively low population density in the degraded areas (averagely 43 persons km^2) would suggest that these are marginal areas with limited carrying capacity to start with. As population pressure increases, more fragile lands will be taken into cultivation leading degradation with below average population densities.

Another project by Q. B. **Le**, L. **Desta** and P. L. G. **Vlek** is the correction of atmospheric fertilization effects in remote sensing-based assessment of land degradation. A long-term trend analysis of biomass productivity (1982-2003) shows that the greening areas are about 22% of the basin's land mass, which is much larger than the areas showing significant biomass decline (8%). Moreover, about 81% of the greening areas experienced no significant correlation to annual rainfall, showing that this profound greening cannot be explained by rainfall dynamics. Global changes in atmospheric chemistry, e.g. rising levels of atmospheric CO_2 and NO_x, are likely responsible for the observed trend in biomass increase. Evidences from other continents on atmospheric fertilization, the observed NDVI improvements in SSA may be plausibly explained by a shift in atmospheric chemistry. Assuming that atmospheric fertilization is ubiquitous in SSA, the process would mask degradation of land due to direct human activities. Against this background, a re-assessment of the vegetation decline in the Volta basin, taking into account atmospheric fertilization, increased the land affected by human-induced degradation from 8 to 65%. The masked degradation areas for the various land-cover types are 106 thousands km^2 for agriculture, 55.5 thousands km^2 for shrubland, 52.5 thousands km^2 for woodland and 10.4 thousands km^2 for arid grassland. At this rate of decline in land productivity, the basin may soon lack the land resources necessary for economic development.

Cluster S: Water Supply and Distribution

The Water Supply and Distribution (S) cluster encompasses the analysis of physical water distribution and availability in space and time, inclusive of atmospheric, surface and subsurface hydrologic processes. It contains most of the elements of the Atmosphere cluster, as well as current work package W1 (Runoff and Hydraulic Routing), extended to include probabilistic analysis of climatic and hydrologic phenomena and investigation of groundwater recharge.

Sub-project S1: Hydro-meterological Modeling (MM5 and WaSiM)

Focus of the research activities was the identification of objective weather patterns that are highly unfavorable for agriculture. Special attention is given to weather patterns that tend to produce extremes in precipitation, resulting in unusually wet or droughty conditions.

Methodology and results:

S. **Wagner** finished his PhD thesis “Water Balance in a Poorly Gauged Basin in West Africa Using Atmospheric Modeling and Remote Sensing Information”.

For the propagation of uncertainties, resulting from the calculation of areal precipitation from point measurements in water balance estimations, Wagner investigated the following issues. First, different spatial interpolation methods for areal precipitation are applied and their impact on water balance estimates is analyzed. Additionally to the standard interpolation methods inverse distance weighting and Thiessen polygons, ordinary and external drift kriging are applied for the spatial interpolation. The areal annual precipitation fields show that the application of external drifts support the spatial interpolation of point measurements. The long-term mean precipitation field provides, in particular in regions with extremely coarse observation networks, important additional information for the spatial interpolation of station data. The performance comparison with cross validation results shows that kriging methods outperform the standard interpolation ones. Thereby, the use of external drifts increases the variance of the areal precipitation fields. The impact of the selected spatial interpolation method for areal precipitation on the temporal and spatial distribution of water balance variables is minor for spatially aggregated variables and the corresponding time series. However, the selected interpolation method affects the spatial distribution of water balance variables. Although the differences are very heterogeneous in space, the impact of the applied external drift is clearly visible.

Second, geostatistical simulations for areal precipitation are performed for the investigation of propagation of uncertainties in water balance estimations. Turning band simulations increase the spatial variability of the precipitation fields, which leads to an increase of spatial variability for actual evapotranspiration and a decrease of variability for total discharge, which is in good agreement with the kriging results.

For sustainable decisions in water resources management, the entirety of all hydrological simulation results, driven by equally probable precipitation fields from the turning band simulations, provides ranges of the temporal and spatial distribution of water balance variables. These ranges are the consequence of uncertainties from the calculation of areal precipitation from station data. The propagation of uncertainties from the areal estimation of precipitation in the spatial and temporal distribution of water balance variables is clearly visible. The partly large range of possible daily precipitation amounts leads to a wide range of possible realizations in particular for the total runoff time series. The comparison of turning band results for routed discharge shows that the width of possible realizations varies considerably depending on the location of the sub-catchment and the uncertainties of the upstream sub-catchments.

In January 2008, together with S. Wagner, P. **Laux** conducted hydro-meteorological training courses in Accra (Ghana) and Ouagadougou (Burkina Faso).

B. **Nyarko** continues monitoring of wetland fluctuation and isotope concentration at the Pwalugu Wetland site. Two divers were installed at Pwalugu and Kubore for the monitoring of water level and conductivity. Currently, he has installed a mini weather station at Pwalugu; in addition to it a sensor was installed to collect continuous soil moisture data at a depth of 20cm.

B. **Amisigo** continued running models such as MM5, using the super-computing facilities at the Ghana-India Kofi Annan Centre. He also contributed to an assessment of the impact of climate change on the new Bui dam in Ghana as part of GVP’s input to the activities of the Dam Forum in Ghana.

Sub-project S2: Hydro-meterological Observatory

The Biophysical Observation Network (BON) within the framework to the GLOWA-Volta project was maintained and extended. The prospected new research site in northeastern Ghana was investigated, and a field site evaluation carried out.

Methodology and results:

The field work of U. **Falk** and J. **Hendrickx** in Burkina Faso, Ghana, Benin and Mali included the following activities: i) revision and data acquisition of the micrometeorological research sites in Boudtenga, Dano, Ouahigouya and in Bontioli Park (Burkina Faso) and in Pendjari Park (Benin); ii) modification and expansion of the precipitation measurement network in Pendjari Park (Benin); iii) Modification and expansion of the precipitation measurement network in Pendjari Park; iv) coordination talks with counterparts (Meteorological Service Burkina Faso and VBA) during a stay in Burkina Faso in January and in Mali in February, and with counterpart in Pendjari Park (Benin); v) setup of joint collaboration with BMZ funded project ALUCCSA (Tropenzentrum Göttingen); vi) setup of association with EU framework project CarboAfrica (www.carboafrica.org); vii) participation in the GLOWA status conference in Ouagadougou, Burkina Faso; viii) participation in the BIOTA status conference in

Stellenbosch, South Africa; ix) the scintillometry site at Boudtenga had suffered severe damage due to a hail storm 2 weeks before, and was re-adjusted and measurements continued; x) the Hobo weather station network and the climate station in Pendjari National Park, Benin, were maintained and data downloaded. Two new Hobo weather stations were setup at Mare Bali in the Park; xi) a new site for the extension of the BON was investigated. The site is in Northern Burkina Faso at Ouhigouya; xii) investigation of the Atankwidi catchment; xiii) the Eddy Covariance site at Boudtenga was reinstalled and improved.

The climate database set up within the first phase was extended with the data sets of the "Biophysical Observation Network" (BON, Figure 4) and data sets of the Institut de Recherche pour le Développement (IRD), the World Meteorological Organisation (WMO) and the Agrometeorology Group, Food and Agriculture Organization (FAO) of the United Nations.

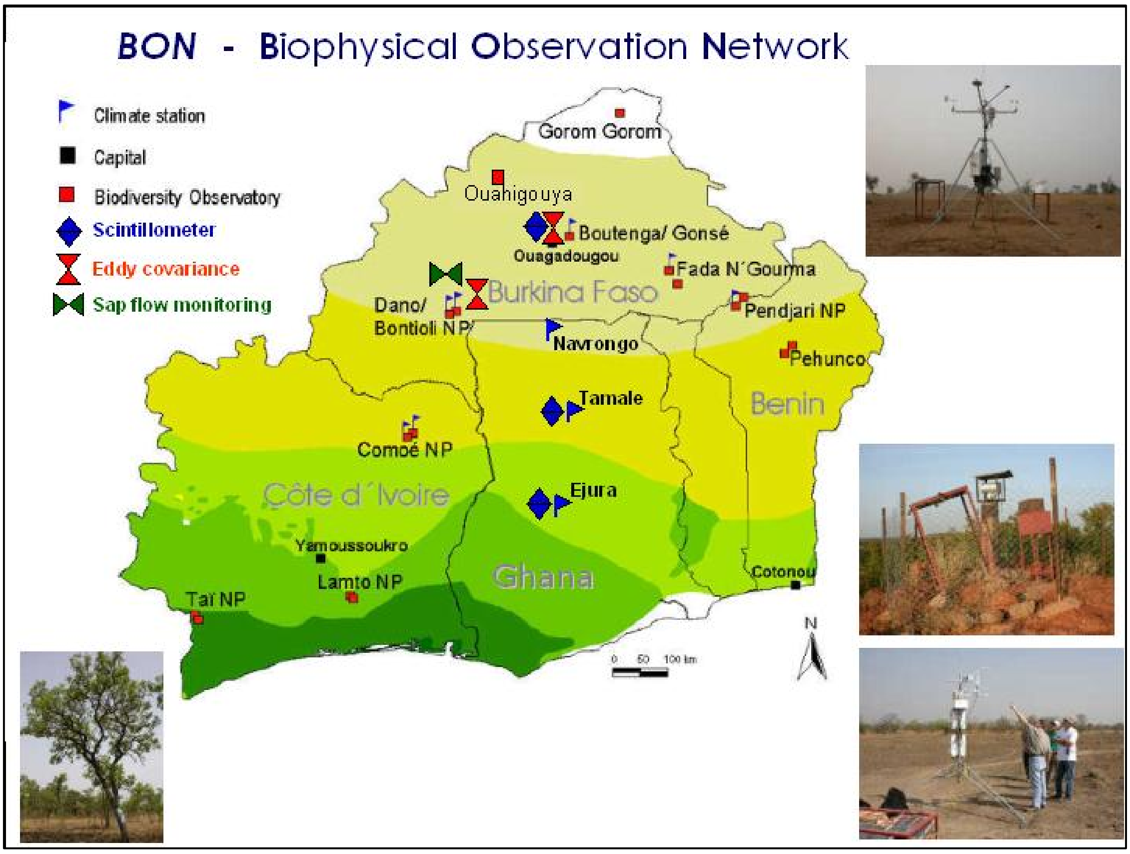

Figure 4: Biophysical Observation Network

Source: Falk 2007

Within the report period, BIOTA internal as well as contacts to external cooperation partners were broadened. Existing connections to counterparts in Burkina Faso - Institut de l'Environment et de Recherche Agricoles" (INERA) and the national Meteorological Service - and Benin - Centre National de Gestion des Réserves de Faune (CENAGREF) were also expanded. Cooperation with other, bigger projects like CarboAfrica, and other universities working in West-Africa, e.g. University of Denmark, were established and strengthened. In addition to the local field assistants, several member of the Meteorological Service were trained in maintenance and supervision of the installed micrometeorological station network. Moreover, members of the Pendjari National Park Managements were instructed in maintenance and operation of supplemental measurement modules. Our technician Mr. G. **Boko** now attends to all stations along the East-West axis of the monitoring network, which guarantees continuous data acquisition, but in doing so, also uses the assembled data base for the basis of his Master thesis at 2iE, the International School for Water in Ouagadougou (Burkina Faso). He is also involved in building technical and analytical capacities in the Meteorological Services at national level, to hand over the BON stations after the end of the projects.

This period was the second year of R. **Kasei**'s PhD project "Models of probability and risk applied to water resources management in the Volta basin under climate change". He returned from conducting field work and data collection. With the help of his supervisors, he completed some major parts of the WaSiM-ETH model for the Volta basin, and ran some scenarios with promising results. Major outputs were: (i) preliminary hydrological outputs from WaSiM-ETH for some catchments in the Volta basin; (ii) a working model for the meteorological part of the WaSiM model; (iii) a soil map for the basin from FAO 1996 for WaSiM inputs.

Sub-project S3: Remote Sensing and Surface Energy Flux

This sub-project is concerned with the measurement and computation of solar and terrestrial radiative and energy household to support the development of remote sensing products.

Methodology and results:

In the context of the meteorological ground measurements, registration and estimation of solar and terrestrial radiative and energy flux components are of great importance. These parameters are also used as ground truth data for evaluation of remote sensing products, for instance at the experimental sites Boudtenga and Bontioli. Initial results of the validation of LandSAF products (Land Surface Analysis Satellite Applications Facility (LSA SAF)) on the basis of MSG data (Meteosat Second Generation) and ground truth data from Burkina Faso as well as flux estimations of CO2, water vapor and energy in Bontioli National Park (Burkina Faso) and above a agricultural site in Boudtenga (Burkina Faso) were presented at two past annual meetings of the European Geosciences Union (EGU).

Sub-project S4: Surface, Soil and Groundwater

The work of this sub-project consisted of the collection and modeling of water fluctuation data as well as the calibration of the SWAT model for a particular measurement station. Vegetation water measurements and GIS work was combined to assess temporal soil moisture dynamics in the Volta basin.

Methodology and results:

Main activities of E. **Obuobie** focused on: i) analysis of data on chloride concentrations in rainfall and groundwater, groundwater-table fluctuations, soil, land use, river discharge and climate gathered for the White Volta sub-basin of the Volta basin; ii) estimation of the total amount and spatial distribution of groundwater recharge using chloride mass balance, water table fluctuation and hydrological modeling with the Soil and Water Assessment Tool (SWAT), as well as evaluating the impact of future climate change on the recharge; iii) writing up his PhD thesis.

The results of chloride analysis in the northeastern part of Ghana (Upper East Region) show that monthly chloride deposition in the region via rainfall in 2006 ranged from 0.2 to 2.1 mg/l, with areal-weighted mean and standard deviation of 0.8 mg/l and 0.43 mg/l, respectively. Chloride concentrations in groundwater ranged from 4.0 to 23.8 mg/l with an areal-weighted mean of 13.2 mg/l and a standard deviation of 9.0 mg/l. Based on the variation of chloride concentrations measured in groundwater, the estimated long-term annual groundwater recharge in the Upper East Region was estimated to be 34.0-182.0 mm, with an areal-weighted mean of 82.0 mm. The mean annual recharge represents 8% of the long-term mean annual rainfall of 990 mm.

Analysis of water table fluctuations in the south of the basin (commonly referred to as the White Volta Basin of Ghana) show that annual water-level-rise ranged from 1,238 to 5,000 mm in 2006 and from 1,594 to 6,800 mm in 2007. Based on standard values of specific yield and the measured water-level-rise, the estimated annual recharge ranged from 28.0 to 150.0 mm in 2006 and from 32.0 to 204.0 mm in 2007. The areal-weighted mean recharge was 70.0 mm in 2006, representing 8% of the annual rainfall (870 mm), and 92.0 mm in 2007, representing 7% of the annual rainfall (1,294 mm).

The hydrological model SWAT model was calibrated (1986-1999) and validated (1992-1999) at Nawuni for the entire White Volta river basin. The simulated mean annual recharge to the shallow groundwater was obtained to be 59.0 mm, about 7 % of the mean annual rainfall (824 mm). Generally, the southern parts of the basin receive more recharge compared to the northern parts (Figure 5). This is reflected in the distribution pattern of rainfall and soil type. The south receives more rainfall than the north and has two peaks as against one in the north (Figure 6 and Figure 7). The soil types in the north are higher in clay content compared to those in the south. Through use of SWAT-simulated annual hydrological fluxes for the present time period (1991-2000) as the basis for comparison, the simulated future (2030-2039) fluxes, and the variations in the fluxes show important increases as a result of future climate change in the basin.

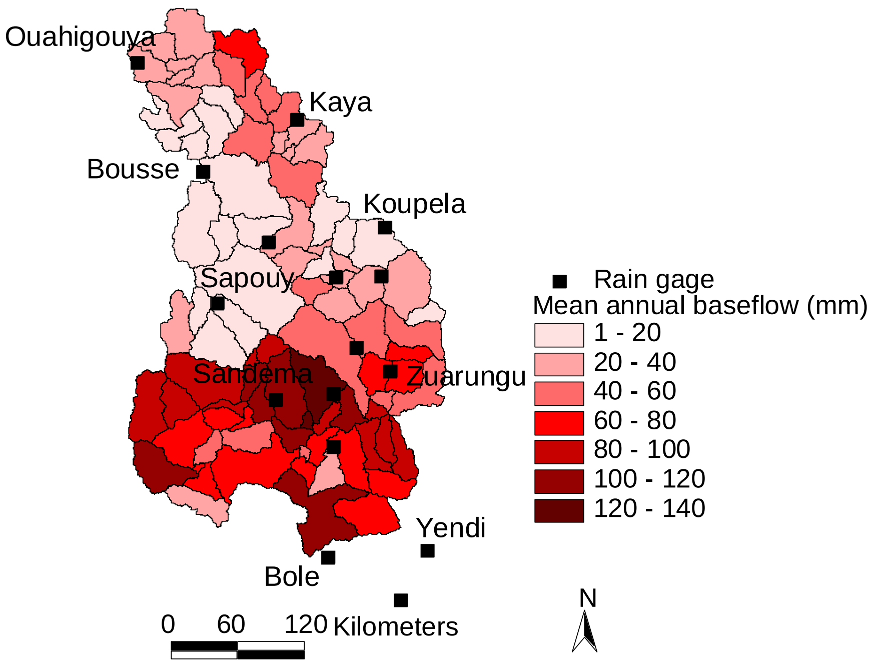

Figure 5: SWAT-simulated mean annual shallow groundwater recharge in the White Volta river basin (1980-1999)

Source: Obuobie 2008

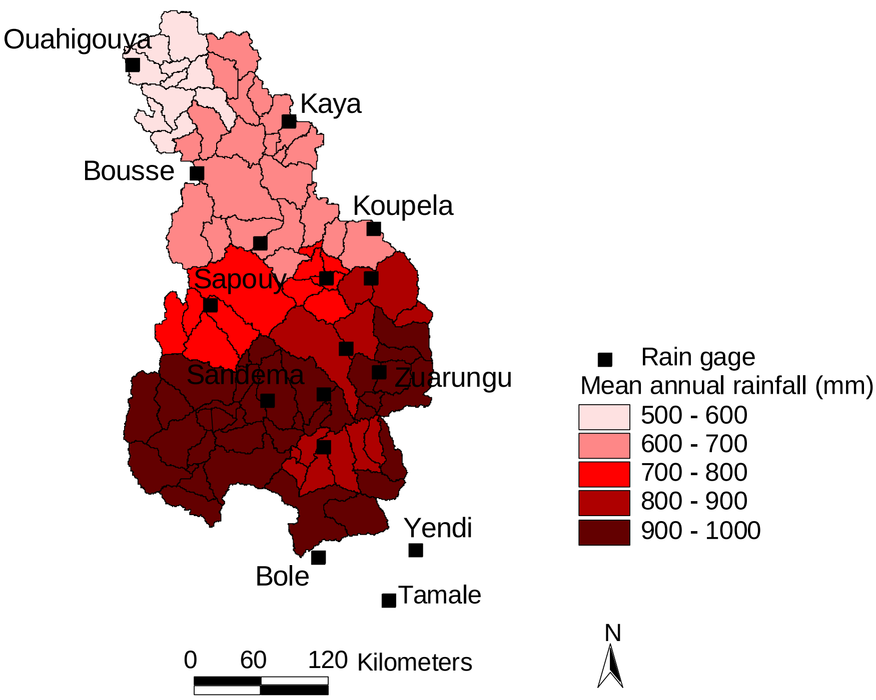

Figure 6: SWAT-simulated mean annual rainfall in the White Volta river basin (1980-1999)

Source: Obuobie 2008

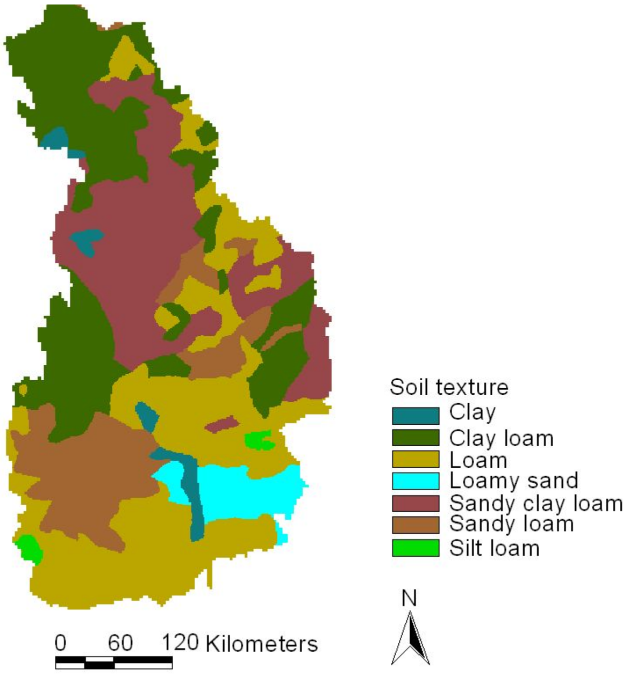

Figure 7: Texture of soils in the White Volta river basin

Source: Schuol et al. 2008

Research activities at TU Delft mainly concern J. **Friesen**'s PhD project: "Large-scale soil moisture detection and monitoring using ground observations and satellite data in the Volta Basin". The research activities in 2008 were mainly concerned with regional modeling of the soil-vegetation-atmosphere system on the scale of West Africa. Regional models for soil water and plant water were designed and coupled to show the effect of diurnal variations in vegetation water onto satellite soil moisture estimates.

Modeling of the soil-vegetation-atmosphere system aimed at retrieving the water stored in vegetation. Through the comparison of modeled vegetation water and diurnal satellite data, the effect of vegetation water onto satellite soil moisture estimates was investigated. Satellite backscatter data, used to estimate soil moisture, is available from two times, in the morning at 10.30 am and in the evening at 10.30 pm. The difference between satellite observations at the two retrieval times shows spatial and temporal patterns that suggest vegetation water to be one of the main causes.

Modeling focused on two approaches: i) a physical approach (Figure 8), and ii) a conceptual approach (Figure 9) based on findings from the physical model. The physical approach models water flow from the soil through tree vegetation into the atmosphere. Vegetation water is modeled diurnally, in 30 minute time steps, for 2006. The conceptual approach uses results from the physical modeling approach, namely the response of diurnal vegetation water fluxes onto limited soil water availability, and combines the different vegetation water fluxes with available soil water from a regional soil water model.

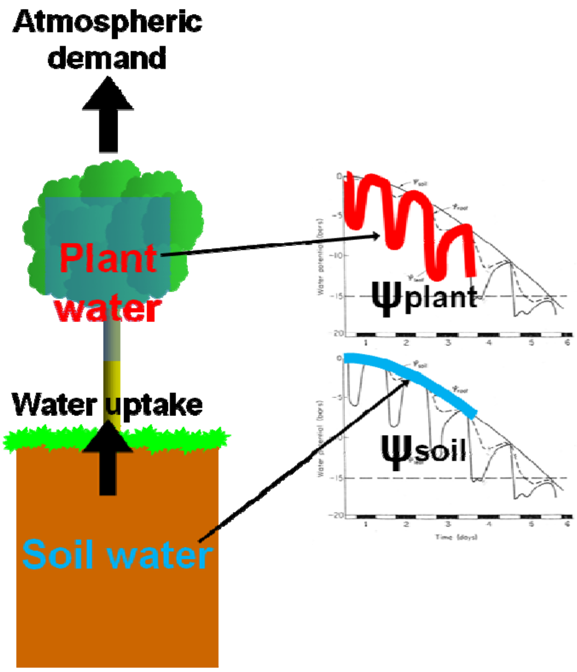

Figure 8: Physical approach. Diurnal plant water fluxes as influences by declining soil water. On the left water movement along a tension gradient from soil to tree into the atmosphere is shown. On the right, the diurnal flux schemes depict soil water tension (ψ)

Source: Friesen 2008

Results from the physical approach support the hypothesis that vegetation water is one of the main causes for the detected satellite patterns (Friesen, 2008 – chapter 4). Diurnal fluxes of tree vegetation water respond to soil water availability.

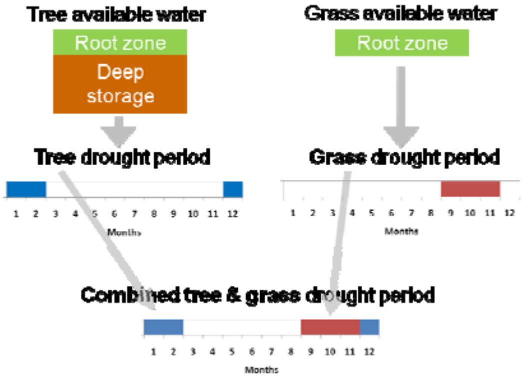

Figure 9: Conceptual approach. Combined tree and grass drought periods as determined by different drought definitions for trees and grasses

Source: Friesen 2008

Figure 9 shows that under saturated soil water conditions, the evening vegetation water status is above the morning water status. When soil water becomes limited, the diurnal flux pattern of vegetation water shifts and the evening vegetation water status drops below the morning vegetation water status. This shift in the relation between morning and evening vegetation water status corresponds to the temporal patterns detected in the satellite backscatter data.

The conceptual approach uses the results from the physical approach, postulating that under water limited conditions, the diurnal vegetation water flux shows a shift in the relationship between morning and evening vegetation water status (Figure 10). Using a conceptual drought period concept (Figure 9) the results from Figure 10 are linked to a regional soil water model.

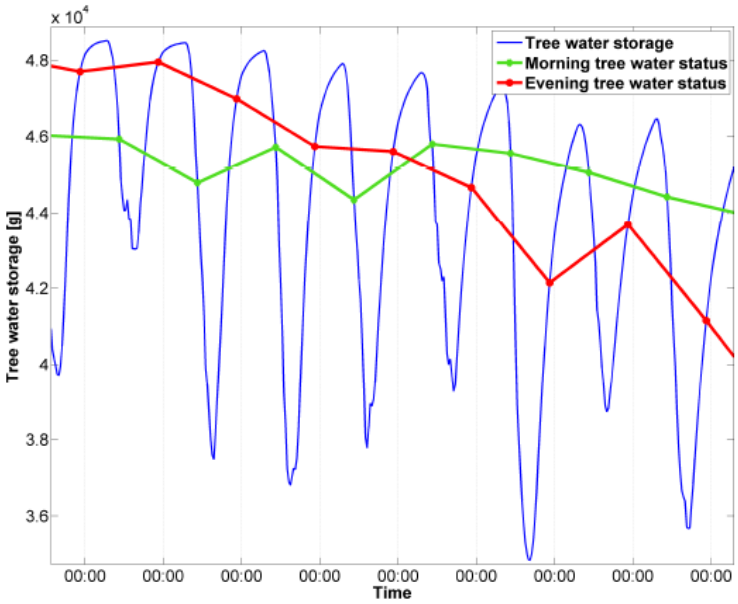

Figure 10: Diurnal tree water flux in [g] during a period of declining soil water content. Green and red dots show tree water storage at morning (green) satellite overpass times and at evening (red) satellite overpass times

Source: Friesen 2008

The conceptual drought period approach (Figure 11) shows drought stress, and a corresponding shift between morning and evening vegetation water status, over a large area with high intensity in November. This area shrinks until February. The conceptual drought period maps allow for a spatial and temporal drought period distribution. In comparison with diurnal satellite backscatter differences the drought period concept shows good agreement in months of high backscatter anomalies (October to February).

The modeling results show that vegetation water can be seen as one of the major factors that influence the detected diurnal satellite backscatter differences. In view of future satellite validation campaigns and field studies that are required to fully prove the link between satellite backscatter patterns and vegetation water, it can also be concluded that diurnal variations in vegetation water have to be included. For further details of this study the reader is referred to Friesen (2008).

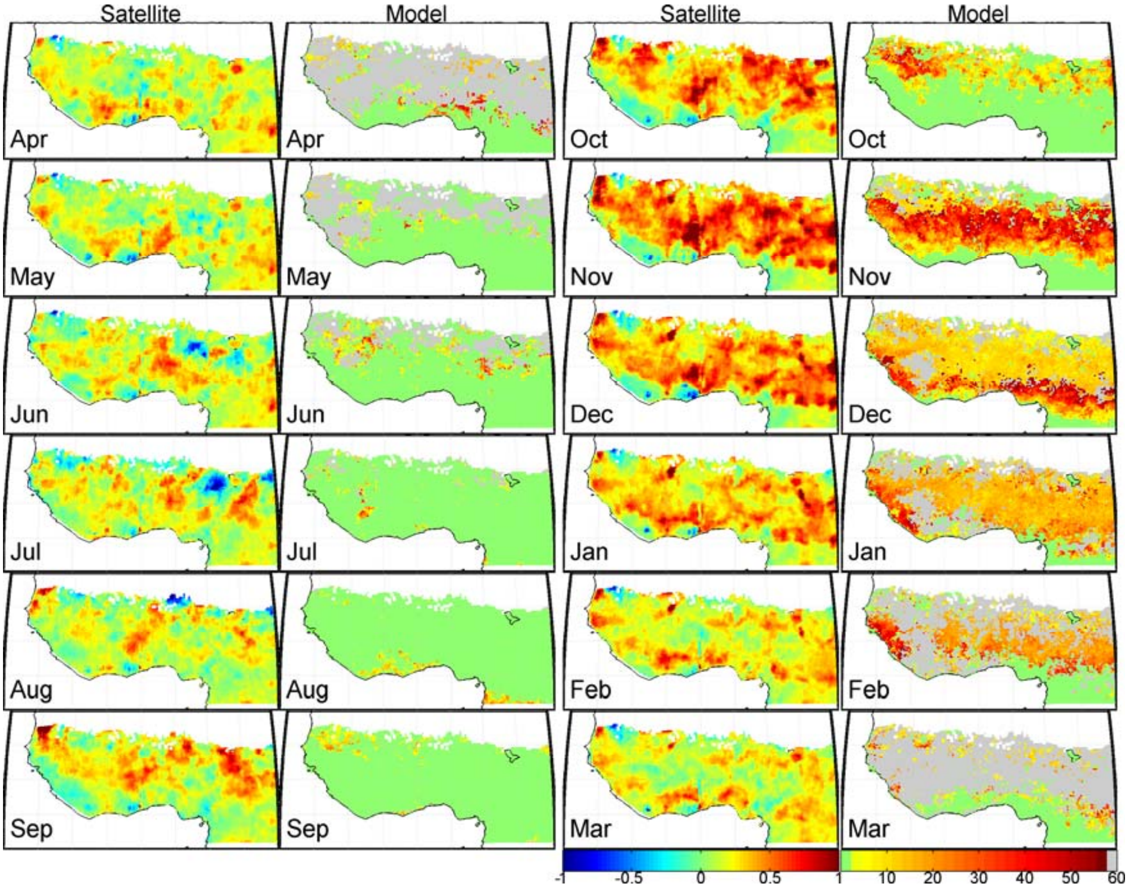

Figure 11: Monthly averaged diurnal ERS backscatter differences (1992-2007) and monthly vegetation drought period maps

Source: Friesen 2006

Cluster E: Analysis of Long-term Environmental Change

The focus of studies in this cluster is on environmental changes endogenous to the Volta Basin that evolves over decadal time scales. These changes, such as alterations in land cover, soil degradation and loss of wetlands reflect complex interactions and feedbacks between climate, human settlement and economic activities. Cluster E carries forward much of the work currently conducted within the Land Use cluster. Primary objectives are the provision of credible future land cover scenarios required by climate and hydrology models, and the provision of decision support tools for proactive land management on the local and basin scales.

Sub-project E1: Automated Classification of Remotely Sensed Imagery

The Würzburg cluster provided data for the phase II clusters L1/ Land use change detection and quantification, L3/ Vegetation dynamics and L5/ Land use change prediction model. Work for these clusters was continued in phase III.

Methodology and results:

The Würzburg group (T. **Landmann**, M. **Machwitz** and M. **Schmidt**) continued with research of great relevance for the DSS. From the 26 Landsat tiles from the years 1990 and 2000/2001, respectively, we derived land cover change information, using broadly defined processes of change such as land transformation and land modification. The change processes were for the whole GLOWA study area, whilst for one area around Tamale in Northern Ghana we investigated the change processes from 1970 to 1984 and to 1992 and then from 2000 to 2005. The original land cover was recoded to 10 functional classes and aggregated, from 250-meter resolution, to 10-kilometre resolution.

From the change processes we inferred non-linear statistics on change drivers. We used socio-economic as well as biophysical data for the driver analysis. A matrix was derived showing the reasons for change processes mapped from remote sensing as a function of the statistical significance of a particular driver.

The wetland data set derived in the year 2007 from 250-meter MODIS satellite data was validated using independently captured and higher resolution Landsat data at three sites in Burkina Faso.

Based on two field-campaigns (2007 and 2008) several ASTER-satellite-scenes were classified. Based on this training data set, the classification tree algorithm (CART) was applied and enhanced. Actual land cover information of larger areas of the Volta basin could be obtained with MODIS 250m data for the year 2007.

From aggregating the original 36 class land cover data, a 10 class land cover was produced and disseminated to the project consortium. The 10 class land cover was further aggregated to 10-kilometer pixel size, so that these results can be implemented for regional to continental hydrological modeling.

Results from the land cover change analysis using socio economic data showed that population density and proximity to urban areas was the primary driver of conversions from natural woodlands to agricultural areas. Modification processes such as thinning of tree cover measured over a 10 year period from remote sensing was related to the proximity to infrastructural developments such as roads. The enrichment of woodlands at the expense of forests was the primary driver responsible for selective logging, although the socio-economic driver was largely unknown in the conversion of forests herein.

Rates of change were inferred from the land cover change and showed several ‘hot spot’ areas in northern Burkina Faso, where natural savannah systems were largely transformed to agricultural areas. The rates were measured in percent change over a specific period, and the expansion of cotton fields in Burkina Faso was presumably the reason for the land cover change ‘hot spot’.

Based on climate data for the last 20 years (worldclim) and soil information from the FAO, the potential land cover was modeled using the tree classifier algorithm (CART). Land cover information of National Parks was used as training data. The result is a land cover map with the distribution of the natural classes without human influence and only based on climate and soil conditions. This data set can be used for the analysis of human influence on land cover and to also account for potential carbon stocks.

Further input parameters for NPP modeling were generated like percentage cover, soil parameters, downscaling of FPAR and processing of climate date. Therefore the next step will be the NPP modeling itself.

Sub-project E2: The Basin Wide Cellular Automata LUCC Model

This cluster works on the modeling of cellular automation of land use - land cover changes in hotspots areas of White Volta sub-basin. The work included the classification of time series land use data, assembling data of potential drivers and the specification of functional forms.

Methodology and results:

The Basin Wide Cellular Automata LUCC Model aims to model land use change and evaluate the main driving factors in the White Volta basin. The modeling exercise by Q.B. **Le**, L. **Tamene** and T. **Landmann** required multi-temporal images and socio-economic factors that determine land use change processes. The main task accomplished with regard to cellular automata modeling was the collection of images covering the target area (from 1970s to 2000s) and gathering of available biophysical and socio-economic data for the region around Tamale. The modeling exercise was performed in February 2008.

Sub-project E3: GV LUDAS. A High Resolution Agent-Based Model

The work of this cluster in 2008 was characterized by additional data collection, the continuation of the database preparation, the verification of model variables and parameters using multivariate statistics. Analytical case studies continued.

Methodology and results:

An operational version of a multi-agent-based simulation model applying the GV-LUDAS modeling framework was produced (**Schindler**, in press). The model was applied to a meso-scale area in Upper East Ghana (Atankwidi catchment with an area of about 150 km^2) and a modeled resolution of 30m x 30m. Considered external factors were the introduction of small dams, credit schemes, changes in population growth rate and annual rainfall.

BF-LUDAS model: Another operational version of the GV-LUDAS framework was developed for landscape-scale areas in the Ioba Province of Burkina Faso (Wahable and Sorians villages, each village covers about 50 - 70km^2) and the modeled resolution was of 15m x 15m (**Gleisberg**, in preparation). Considered external factors were the introduction of agricultural extension and fertilizer subsidies for cotton cultivation, demographic and annual rainfall change.

Simulation outputs consist of a spatially and temporally explicit land use/cover map, visual graphs, and export files of selected land use and livelihood indicators. These convenient output visualization tools, together with the user-friendly interface of GV-LUDAS, allow stakeholders to simulate and analyze selected scenarios, which can serve as a basis for discussion and communication among stakeholders and policy-makers. The effect of land use change drivers (e.g. population growth, rainfall change and policy interventions) on the overall economy of the community and on different social groups could, therefore, be gauged adequately. By providing multi-dimensional outputs over the long run in response to the change of external driving forces, the model has a good capacity in assessing the resilience and vulnerability of the social-ecological systems in a comprehensive way.

During the specification and calibration of the GV-LUDAS components, empirical analyses and sub-model testing resulted in not only calibrated parameters of household's land use behaviors, but also additive knowledge about socio-economic and landscape patterns that should be useful for integrated natural management in the study areas. The newly generated knowledge includes:

(1) the plausible and holistic classification of households in the study areas into representative livelihood groups that form a basis for agent-based modeling as well as aiding the identification of relevant target groups in land/water management projects/programs,

(2) the identification of social, biophysical and policy determinants of household land use choices in the areas. In general, the results show that land use decision outcomes are livelihood typology-specific and both landscape and social heterogeneities have a crucial effect on farmer's adoptions of land uses.

(3) The estimations of crop production functions (yield response functions) against not only cultivation inputs (e.g. labor, fertilizers, pesticides), but also site conditions (e.g. soil erosion risk, nutrient deposition and topographical wetness) and management practice (e.g. inorganic fertilizer uses). As the relationship between crop productivity and such factors were established, the multi-dimensional production functions were used, as one among some others, fore-closing the social-ecological feedback loops in the multi-agent-based model. The empirical results also show that most of agricultural land in the areas are marginal to inputs, thus soil conservation and land restoration are the urgent needs.

These empirical findings are presented as self-sustained chapters in Schindler (in press) and Gleisberg (in preparation).

To improve our understanding of the complex human-environment system, compliance or resistance to policies, the development of an agent-based model (ABM) requires credible representations of micro-processes through comprehensive empirical analysis. Based on a conceptual model derived from the Sustainable Livelihoods (SL) framework, empirical livelihood and land use adoption analyses were conducted by K. **Gleisberg** using survey data collected in the province of Ioba during the rainy season 2006 and dry season 2007. To capture topographical variables determining the distribution of soil and water over the landscape, terrain indices were calculated using a combination of satellite imagery, topographical maps, a digital elevation model and GPS measurements in the field.

Furthermore, policy issues having major implications for rural farm households and the natural landscape in the study region were identified: Access to new technologies and knowledge on soil conservation methods. Accordingly, variables representing these policies were created, namely access to agricultural extension services and access to mineral fertilizers. Guided by conceptual considerations of the impact pathways, indicators were selected to measure the impact of the policy issues. These indicators recognize both environmental and socioeconomic outcomes of the policy interventions at the local and regional level: Farm income (F CFA), Income composition (percentage of farm and non-farm income sources), Income equity (Gini coefficient), Labor allocation, and Land cover change (spatial distribution of land cover categories).

Livelihood and land use adoption analysis were based on a data set of 111 households in three representative villages in the province of Ioba, in south-western Burkina Faso. Relevant plot data were recorded for 964 plots.

For the livelihood analysis, representative variables for each of the five capital assets suggested by the SL framework were selected. Running a principal component analysis resulted in the identification of six crucial determinants of livelihoods, namely non-farm income, labor, land resources, physical capital, dependency, and education. In order to reflect the heterogeneity of farm households affecting the adaptation and adoption of strategies in the ABM, households were categorized. Using standardized scores of the six principle components, a k-means cluster analysis resulted in three different livelihood groups: cotton farmers, cereal-livestock farmers, and non-farm farmers. The first livelihood group comprises households with a strong involvement in cotton production that substantially guides resource allocation. Because of their strong orientation towards cotton, these households are exposed to risk from global market price fluctuations for both inputs and output. In terms of resource endowment, group I households are characterized by the highest labor availability, largest landholdings and the lowest per capita income. The second livelihood group is made up of farm households largely focusing on agricultural production to meet their food demand. In terms of their relative importance, cereal and cash crop production are more or less balanced. They are characterized by the lowest labor availability and limited landholdings but pursue a more diversified livelihood. The third livelihood group differs from the two other groups by smallest landholdings as well as highest education and per capita income. They maintain their livelihood through balancing market and subsistence activities by allocating more resources to cash income generating activities.

Land use adoption analysis at the plot level using a binomial regression model that includes environmental attributes of the plot, socioeconomic characteristics of the household and land use related policy variables for each livelihood group, shows different behavioral patterns of the groups reflecting their livelihood strategy.

The findings suggest that both selected policy factors, access to agricultural extension services and access to mineral fertilizers, may not be appropriate policies to adopt certain land use and land use practices. Despite the intense promotion of cotton cultivation and related land use practices, traditional land use practices and subsistence cropping are still predominant aspects in natural resource management of households.

The next step of the research is to run simulations with the integrated results of the empirical analysis in the ABM simulation program and analyze scenarios under varying policy conditions and vulnerability contexts.

In 2008, J. **Schindler** finalized the GH-LUDAS (GHana – Land Use DynAmic Simulator), which is an agent-based decision support tool for land use/cover change in the Atankwidi catchment in Upper East Ghana. The programming work in NetLogo was completed within the period from January to April 2008, while the remaining part of the year was dedicated to the preparation of her PhD thesis and simulation runs with GH-LUDAS. The simulations comprised scenarios of dam construction, credit access, population growth and rainfall reduction. In total, 16 scenarios were run, whereby each was run 5 times to account for variability in results. Each scenario family was analyzed with respect to its effects on land use/cover and socio-economic patterns. The results were documented in the final chapter (Chapter 6) of the PhD thesis, while the remaining part of the thesis was dedicated to model documentation and sub-model calibration. The first chapter of the thesis deals with the issue of land use/cover change in general, the necessity for decision support in land management, and the approaches used in LUCC (land use and land-cover change) research. The second chapter introduces agent-based philosophy, setting the conceptual basis for further model specifications. Chapter 3 deals with the documentation of the entire model, while in Chapters 4 and 5, the human and the environmental part of the GH-LUDAS are explicitly presented and calibrated.

The results of this year's research comprise both practical and scientific results, i.e. the development of a decision support tool (GH-LUDAS) for local decision makers in Upper East Ghana, and analyses of scenarios simulated by GH-LUDAS. The suitability of GH-LUDAS as a decision support tool is due to its user-friendly model interface, which allows users to set parameters for scenarios they want to explore, without a necessary understanding of the source code. Parameters regulating credit access, dam construction, population growth and rainfall reduction can be set externally, and outputs in terms of land use/cover and income patterns are visualized in temporal graphs, together with a real-time spatially explicit map of land use and cover. If desired, annual values of any model variable can be easily exported for further analysis into SPSS or Excel.

Furthermore, integrated scenarios were developed for different (policy) options, with the purpose of identifying the range of possible future pathways triggered by policy and other external factors (policy-related purpose), and of identifying the main mechanisms leading to these specific pathways of livelihood and land use (scientific purpose). Schindler conducted the scenario development in a systematic and organized manner. First, she defined a baseline scenario, reflecting the policy settings as they were in 2006, and assumed no changes in climate or demography. This baseline scenario was then used to compare the pathways of other hypothetical scenarios with that of the baseline. For this, each external factor was shifted from the baseline gradually to form a scenario spectrum to assess the impact of the change in this single factor. Among others, simulation results suggest that the policy of dam construction was much less effective with respect to average annual income than that of credit provision, although it was the much more costly option in comparison to a credit scheme. In addition, a decline in annual rainfall seemed to trigger a shift towards cash cropping and non-farm activities, which could compensate for the losses in harvest caused by decreased precipitation. For further results see PhD thesis of Julia Schindler.

Field research for the PhD thesis ”Irrigate or migrate? Knowledge and decision making about livelihood earning strategies during the dry season in Northern Ghana” was carried out by B. **Schraven** as co-coordinator for the conduction of a shallow groundwater irrigation related household survey in the Anayare and Atankwidi river catchments. In 2008 he continued to finalize his PhD thesis and generated maps and datasets for the GLOWA Volta geoportal based on several household surveys, which were conducted in the Anayare and Atankwidi river catchments (Upper East Region, Ghana).

Farmers in the Upper East Region of Ghana are increasingly adopting dry season farming along the White and Red Volta rivers using pump irrigation systems to improve household food security, and to provide off-season employment for the teaming of youth who are idle during this period of the year.

The study of W. **Agyare** looked at the growing trend of this activity in relation to the economic benefit to farmers of the adoption of these practices, amidst growing concern of water availability for alternative uses such as flow into the Volta dam for hydropower generation.

Many small dams and dugouts were constructed in the Upper East region to address the problem of water scarcity in the region. The reservoirs are for the provision of water mainly for irrigation and livestock watering, aquaculture, and domestic use. However, many of these reservoirs dry up in the dry season, affecting the livelihoods of the local inhabitants. One of the causes of the drying of reservoirs is siltation, thus reducing the storage capacity of the reservoirs. This study assessed siltation and nutrient transport to reservoirs, so that the appropriate management plans can be adopted to mitigate or reduce siltation. Bathymetric and pit survey, and reservoir soil sampling were conducted to estimate the annual siltation rate and nutrient transport in selected reservoirs.

The pump irrigation study identified that the actual spatial spread of this irrigation practices along the riverine areas in the Upper East is on the increase. Pumps used by farmers have different discharge capacities. The amount of water use per unit land for pump irrigation depends on the type and distance of the delivery system, and the crop type. One need to abstract 5,300-7,500 m^3 and 9,000-15,000 m^3 of water per ha in the dry season to cultivate tomatoes and maize. Dry season farming is a major component of the livelihood strategy of people of Upper East of Ghana, and pump irrigation is rapidly being adopted as one of the methods for addressing poverty. To prevent water pollution, farms must be located at least 50 m away from the river banks, and the use of pipes must be encouraged to limit non-economic use of water.

Four reservoirs studied have lost their dead storage capacity which is designed to store sediment until they have reached their design life. Decreasing storage capacity by siltation affect the livelihoods of local inhabitants since reservoirs cannot serve all their intended purposes.

Enrichment ratio (ER) values >1 were observed for the plant nutrients and the finer soil fractions. The high ER is associated with the preferential transport of nutrients bound to finer soil fractions and the parent material dissolution and its transport through runoff. However, the fertility status of the deposited sediment, although comparatively higher than that of the catchment, is not sufficient to support crop growth without N and P fertilizer application. The rates of nutrient export (NE) were low and have a positive relationship with Specific Sediment Yield (ASY).

Q. B. **Le** and L. **Desta** integrated some of the most commonly used soil erosion and deposition models into NetLogo, an agent-based programming platform, producing a LAMPT's prototype. The operational model was designed in such a way that fast and robust sensitivity analyses can be performed, after users are allowed to i) select and set different physical parameters, and ii) choose different sets of land use management and planning options. The physical parameters choice meets the scientific needs of landscape modelers in their exploration of adequate values of the many parameters in soil/sedimentation models that are often not well-calibrated in developing regions. The latter is expected to meet the needs of practitioners in catchment management and planning. As the tool allows front-end users to handle the selection of management/planning options, and provide a fast and responsive outputs (in terms of both maps and graphs), LAMPT can assist in effective multi-stakeholder negotiations over land use planning where the minimization of the degradation of land/water resources is the ultimate goal. The LAMPT model can be easily coupled with LUDAS, an agent-based land use change model using the same platform, to comprehensively simulate environment–community loops. During the further development of LAMPT, the research team intends to follow a participatory approach to enhance the relevance of the tool to local community needs. To plausibly calibrate LAMPT at the catchment/community levels in the data scarce environment of West Africa, additional long-term research catchments are essential.

The Revised Universal Soil Loss Equation (RUSLE) and a Distributed Sediment Delivery Model (DSDM) is used by Q. B. **Le** and L. **Desta** in a GIS environment to estimate the spatial distribution of areas experiencing different levels of soil loss in the White Volta basin. The RUSLE is employed to map the spatial patterns of major sediment source areas based on data calibrated for the study region. As RUSLE only estimates the potential gross erosion of each grid cell, a DSDM is used to estimate the sediment delivery efficiency of each cell using flow distance and velocity along the flow path. The combined models allow a classification of sub-watersheds experiencing different levels of soil loss using a soil tolerance threshold suitable for the study areas (Burkina Faso and Ghana). The result shows that the majority of areas around the northeastern and eastern parts of the White Volta basin (mainly southeastern Burkina Faso and Upper East Region of Ghana) are associated with high levels of sediment yield (> 15 t ha^{-1} y^{-1}). The main reason could be high population pressure, poor surface cover and relatively high slope of some of the areas in Ghana. On the other hand, the northwestern and southern parts of the basin experience low levels of sediment yield (< 5 t ha^{-1} y^{-1}) mainly due to their flat terrain and good surface cover that encourage sediment deposition rather than erosion. The study reveals that a GIS-based soil erosion and sediment delivery model can successfully be used for identifying and prioritizing critical sub-watersheds for management purposes. Such a tool can be of significance in developing areas where problems are severe but resources are scarce.

Many small reservoirs have been constructed in the Volta Basin and many more may be built to curb the impact of water shortage due to low rainfall and its high variability. However, high soil erosion may restrict the envisaged services of the reservoirs, resulting in the loss of not only their benefits, but also money spent for their construction. There is thus a need to apply relevant management measures to reduce rapid sedimentation of reservoirs. To achieve this, the severity of the problem should be evaluated. Against this background, over 20 reservoirs were surveyed in the White Volta basin by L. **Desta**. The sediment deposition in those reservoirs was quantified, and currently analysis is being conducted to determine the spatial variability across different locations. The results can be used to evaluate the sedimentation risk of the Volta Lake as well as assess the potentials of the reservoirs for irrigation activities.

Cluster D: Water Demand

The D cluster consists largely of integrative activities that build extensively on research conducted within Phase II on operations research modeling of water-demanding economic sectors. It integrates Phase II work packages W2 (Water and Livelihood), W3 (Institutional Analysis), D2 (Household Decision-making and Policy Response), D3 (White Volta Policy Pilot), D4 (Policy Dialog at Basin Level) and some aspects of D1 (Technical Integration of Socio-Economic and Environmental Modeling Sub-Systems).

Sub-project D1: Agricultural Water Demand

The main focus in 2008 was to negotiate with local partners for data, which is required for the GAMS model on agricultural water demand in Ghana as well as to replicate the existing MATA model of Burkina Faso for Ghana. Additional secondary data on agricultural crop yields were collected.

Methodology and results:

The PhD project of P. **Woedem Aidam** is on the Impacts of Agricultural Sector Policies on the Demand for Water Resources within the Volta Basin of Ghana, West Africa. In 2008 she returned to her field site for the collection of some primary data as well as secondary data that was not available during the first field visit. On her second visit, she was able to collect all the data that she needed for her work. The data collection took her to thirty different communities in the Volta basin area in order to ascertain the necessary information that was required. Most of the secondary data she collected was from institutions that were water and agricultural related.

The broad objective of the proposed research is to identify and, wherever possible, quantify and model the factors that act to determine the demand for water in the Ghanaian agricultural sector, both in the short- and long term. This will enable decision makers to appreciate which agricultural sector policies increase or decrease the demand for water and what could be done to enable sustainable use of the available water resource in the Volta basin. Specific objectives include the following:

- To evaluate the impacts of specific government policies (irrigation, pricing, subsidy, credit) and strategies, in combination with international market conditions, on the domestic production (supply) of, and consumer demand for important agricultural commodities; and the corresponding impacts on water demand within the Ghanaian region of the Volta basin.
- To build an economic model to simulate prospective water demand and supply in the Ghana part of the Volta basin and to maximize farmers' profit estimated as the gross margin of the farm.
- To calculate the optimal use of water for agricultural purposes within the Volta basin, to make available information about possibilities to restructure agricultural production such that economic efficiency of water use can be improved

- To simulate alternative policy prospect to assess the associated income changes of agricultural producers.

The model being employed for the objectives is the MATA-WATER model; this model is a partial equilibrium model that combines four different modules and links them together to produce the results required. The three different modules are coded in GAMS; these models are the production, consumption, macroeconomic and the water module. These modules can be linked together, and the agricultural sector policies used as scenarios and simulations can be analyzed towards their impact on production, consumption and water demand.

Sub-project D2: Non-Agricultural Water Demand

At the center of this cluster stood non-agricultural water usages, such as urban drinking water, water for gold mining and fish production. The case studies highlight negotiation processes among various stakeholders within the water sector, specific institutional frameworks as well as social-ecological independencies.

Methodology and results:

W. **Tsuma** conducted research in the gold mines of Western Ghana where he investigated the negotiation patterns between various actors in the sector. He was interested in explaining the behavior of groups, e.g. how civil society groups, local communities, research institutions, government agencies, media groups etc engage in meeting their goals within the sector. This research was based on the premise that continued social and ecological problems in mining areas resulted from competition between various actors who possessed conflicting interests in these mining areas.

Specifically, research activities sought to:

a) identify and map out the various actors, their roles and respective interests within the mining sector in Tarkwa area of Western Ghana.

b) probe and identify the “spaces” and “drivers“ where negotiations take place and decision making is influenced respectively to meet the interests of local communities, mining companies and the government within mining sector.

c) investigate the various modes of engagement within these negotiations as well as identify the bargaining strategies and tactics employed to shape positions and interests within the negotiation space.

d) explain how various actors meet their interests and influence decision making in their favor within the gold mining sector in Tarkwa area.

Main results of W. Tsuma’s research included:

1. The social and ecological problems associated with the mining sector, as is the case in Ghana, which are a product of complex interaction between multiple actors within the mining sector. These actors possess competing interests of differing power abilities that not only determine the resources being accessed, but who gets to benefit from the extraction investments.

2. Multiple interests by multiple actors influence decision making within the mining sector. These include: NGOs, mining companies, chiefs, universities / research institutions, traditional authorities, government agencies and politicians. These groups of actors are interest groups in themselves and act with an aim to meet specific goals.
3. Decision-making within Ghana's mining sector is therefore an outcome of unequal power struggles between these groups of actors, and not the idealized government legal systems of decision-making. In this case, the distribution of benefits emanating from the mining investments is determined largely by these power struggles more than anything else.
4. Patterns of exchange and benefit distribution within the mining sector is shaped by strategic groups. Strategic groups emerge as an outcome of the unequal power struggle within the mining sector. One common composition of strategic groups is university lecturers, NGOs, mining company officials and traditional authorities, who not only determine the patterns of exchange, but also influences decision making within the sector.

In the beginning of 2008, J. **Hauck** worked on the analysis of data collected in 2007. Data gaps were identified in order to prepare for another field trip. This field trip had two main purposes. One was to present preliminary results to the communities studied, to the Ministry of Fisheries and the GTZ, which started a pilot project for fisheries enhancement in northern Ghana. The second aim of this field trip was to collect data to fill the data gaps where possible. However some of the data gaps could not be filled, as the time was too short for extended measurement campaigns. Because statistical analysis of ecological data is very difficult due to incomplete data and a low number of case studies, it was decided to use local expert knowledge to rank factors that influence fish production in the reservoirs. A range of group discussions with various experts, ranging from local fishermen to Ghanaian fisheries scientists, were conducted and the mapping of influence factors proved to be a useful tool to supplement the data sets. Other data collected included the dissolved oxygen levels of the three reservoirs in a 24 hour cycle and the biological oxygen demand. Data were also collected on fish catches drawing on the memories of fishermen in order to gain an overview of average catches as well as differences in catches of 2007 and 2008.

The field trip took place over two months, from mid-March to mid-May. Afterwards, data was entered and processed using various software and methods. In collaboration with the excellence cluster of the University of Trier a software tool called VennMaker was tested. Data collected in Ghana in 2007 can be visualized with the tool developed in Trier (Figure 12). However, the calculation of network indices was done using the software Visualyzer.

In many communities in northern Ghana, where poverty and malnutrition prevails, fisheries developed into an important supplement to income. The steadily increasing demand for fish further shows that fish is a very welcome addition to the menu.

Unfortunately, the growing popularity of fishing results in over-exploitation, because community-based management of this comparatively new natural resource is poor. The few attempts of science and policy to improve the situation focused on technical solutions to increase fish production and neglected problems of implementation. A look into history and the analysis of networks shows that clashing traditional, governmental,

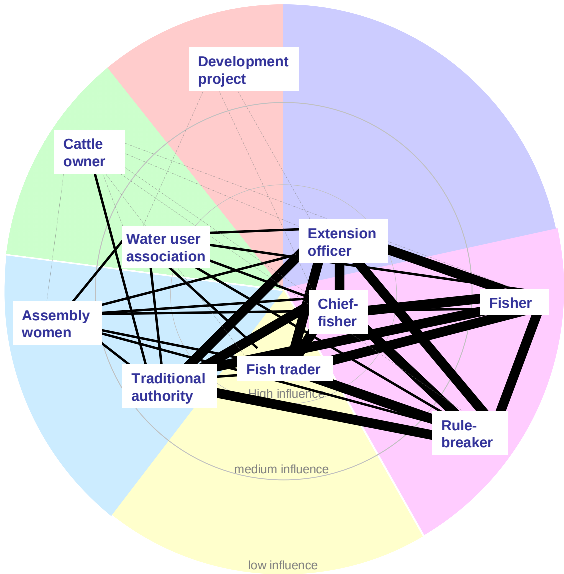

Figure 12: Information network, influencing fisheries activities in Binduri, Northern Ghana

Source: Hauck 2008

and participatory management strategies as well as generation conflicts overtax the capacities of the communities to cope with management responsibilities. Organizational problems and difficulties in the implementation of even the simplest, well-known management rules, such as compliance with the ban on small meshed nets or close season, are some of the consequences.

However missing or failing management is not the only factor influencing fish production. The inclusion of local knowledge helped to rank the availability of nutrients, changing rainfall patterns and the water volume of the reservoir as major ecological factors influencing fish production (Figure 13). For example, water temperature, species composition or fish disease were not mentioned to be highly influential. The integration of scientific analysis and local knowledge proved to be useful to supplement and validate research findings.

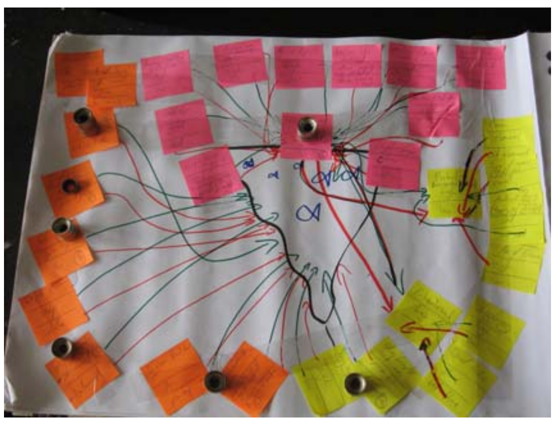

Figure 13: Influence factor map

Source: Hauck 2008

If cooperation between science, politics and local stakeholders can be established to overcome the disenchantment with management, fisheries in small reservoirs has a great potential to support the adaptation of the rural population to climate change.

Sub-project D3: Integrated Demand Simulation Framework

Although preliminary and major activities that would support the data and modeling needs of the Integrated Modeling sub-project have been going on in the past two phases of the GLOWA Volta Project, the design and implementation of an integrated mathematical/ computer programming model were just started in the last quarter of 2007 with the arrival of two new economists.

Methodology and results:

In 2008, research activities of B. **Barbier** focused on 5 different modeling approaches: i) Mata model for Burkina Faso and Ghana; ii) bioeconomic model at the watershed level in the Pontieba sub-watershed (close to Dano); iii) bioeconomic model at the watershed level in the Tougou sub-watershed in the Sahel; iv) dynamic simulations of the Volta Basins in Burkina Faso with an hydro-demographic model and v) hydro and thermal energy dynamic model for Burkina Faso.

New simulations for the Volta Basin with the Mata model including Ghana were developed.

Together with his students, Barbier produced new results for the 3 others models developed at smaller scales. The Pontieba model developed with I. **Dabiré** shows the impact of seasonal forecasts on farm incomes in a small watershed. The stochastic simulation developed by T. **Mandé** in the small sub-watershed of Tougou shows how small scale irrigation reduces risk and allows for more rainfed crop development. Simulations with the energy model developed with K. **Boubacar** show how hydroelectricity and thermal energy compete to satisfy future national demand. Scenarios with caps on carbon emissions show the trade-off between environment and economic efficiency. Another decision support system was developed using Excel and rules to assess the impact of population growth and increasing demand on Burkina Faso's water balance.

N. **Perez** and A. **Bhaduri** devoted the entire project year to three major activities: 1) estimation of major water demand in the basin – domestic, industry, agriculture and hydropower; 2) construction and calibration of the economic model coded in GAMS; and 3) integration of the hydrologic and economic models to form the M^3WATER decision support system, and validation of the integrated model. Most of the year (9 months) was devoted to the first two major activities, while the last quarter until the end of the project in May 2009 is concentrated on model integration, validation and construction of user-friendly interface. M^3 WATER is a Multi-country, Multi-sector, and Multi-use Water Allocation Technology for Efficient Management of Resources. It aims to implement an allocation mechanism that would optimize (maximize) the economic benefits accrued to the entire society as water resources in the basin are distributed among the different countries (Ghana and Burkina Faso), different sectors, and to different uses (both consumptive and non-consumptive).

Although the M^3WATER DSS uses data (parameters and coefficients) derived from the results of the sub-project activities and other studies within and outside the GLOWA Volta Project, the intended 'results' of M^3WATER itself are policy analyses which can be made after the DSS is fully operational. The decision support system is currently functional with limited policy options. However, water demand in the basin (country wise) over the next thirty years has been projected. The results are available in the GVP Geoportal.

Cluster C: Participatory Decision Support and Coordination of Technology Transfer

The success of the GLOWA Volta project will ultimately be measured by the continuity of activities within the region following completion of GVP. GVP has built an effective network of partners in Ghana and Burkina Faso, as well as a consortium of international organizations including KACE, IWMI and UNU. During Phase III, these three institutions will progressively assume leadership of project activities, with the ultimate objective the transfer of ownership to capable institutional partners within all 6 riparian states.

Sub-project C1: Participatory Decision Support and Coordination of Technology Transfer

Sub-project C1 tries to better understand water-related negotiation processes at different societal levels (local, regional, national) in order to come up with ideas for how the needs and capacities of different societal stakeholders can be addressed by the GVP during its capacity building and knowledge and technology transfer activities.

Methodology and results:

Activities of W. **Laube** in 2008 were mainly related to knowledge exchange with various stakeholder groups in the Volta Basin and the communication of research results in a wide range of workshops and conferences. Workshops were held in Bolgatanga and Accra, both in Ghana. The workshop in Bolgatanga targeted local stakeholders such as farmers, local agricultural as well as water administrations and Ghanaian scientists. The impact of climate change in the White Volta Basin, local adaptation via different types of irrigation and the socio-economic as well as environmental consequences of such adaptation were discussed. In Accra, a workshop, organized in cooperation with GTZ and IMWI, focused on the impact of climate change on the generation of hydropower plants in Ghana. During the workshop, climate change scenarios developed by GLOWA Volta were discussed with various stakeholders from government institutions as well as the civil society. Research activities focused mainly on the local adaptation to climate change in the White Volta Basin, and apart from qualitative research and farm monitoring, included a survey of 200 households engaged in shallow groundwater irrigation in the White Volta Basin.

The workshops organized resulted in lively knowledge exchange with local stakeholders as well as with Ghanaian scientists. The workshops are documented in reports that can be found on the GLOWA Volta homepage. Research on local adaptation towards climate change clearly showed that farmers in the White Volta Basin have largely started to engage in irrigation activities as a means of climate change adaptation. The production of irrigated vegetables for the national market allows them to mitigate risks resulting from increasingly unreliable rains during the rainy season. Irrigation could be shown to positively affect local livelihoods as it contributes up to 40% of the agricultural production and reduces the need to migrate during the dry season. However, research has also highlighted limits of adaptation that result from severe marketing problems resulting from increased regional (ECOWAS) and global competition.

Sub-project C2: Transboundary Water Management

The process, actors and challenges of transboundary water management between the riparian countries of the Volta Basin was analyzed. A case study on local transboundary management practices was started in 2007.

Methodology and results:

In 2008, the institutional map on Actors and institutions in the water sector of Ghana and Burkina Faso was finalized by E. **Youkhana** and added the GVP homepage.

Two Master students from the University of Legon and the University of Cape Coast, who conducted research on transboundary water management in the White Volta sub-basin in Northern Ghana, were supervised during their field trip and thesis writing.

A study was conducted on actors, networks and communication structures in transboundary flood management (Figure 14) in the same region in May 2008. The report was written and the main results presented at the International GLOWA Conference in Ouagadougou in August 2008.

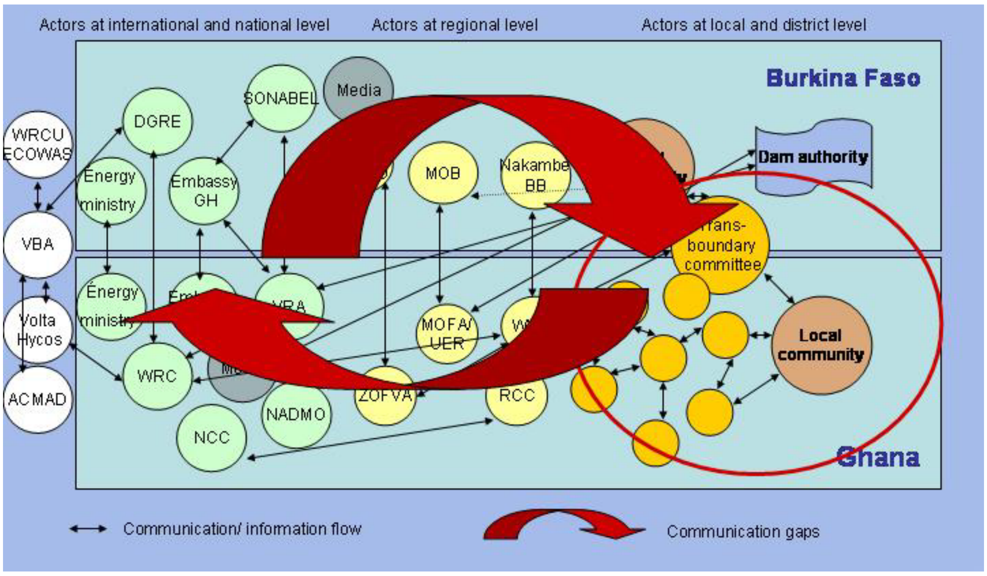

Figure 14: Communication in transboundary flood management

Source: Youkhana 2008

Sub-project C3: Consortium Building, training and outreach in the Use of DSS

Six GVP partner workshops and trainings were conducted, which targeted the capacity building of stakeholders within the Volta Basin.

Methodology and results:

From 14-17 January 2008 UNU-INRA organized a GVP Training workshop on "GLOWA-Volta Project Hydro-meteorological decision support for the Volta Basin" in the ISSER Building, Legon, Accra, Ghana. The workshop was attended by 19 participants and covered the topics: i) model based water balance estimations with training in the water balance simulation model WaSiM and climate change scenario studies; ii) predicting the onset of the rainy season with training in specific statistical approaches, Linear discriminant analysis and Linear Regression Analysis. The workshop was chaired by Dr. Dilnesaw Alamirew (UNU-INRA/ GVP), Sven Wagner and Patrick Laux (Institute for Meteorology and Climatology IMK-IFU).

The same training workshop was organized on the premises of the Direction Générale des Ressources en Eau (DGRE) in Ouagadougou, Burkina Faso from January 22 -25 2008. It was attended by 27 participants from institutions and organizations in the fields of water and meteorology/ climate.

From February 26 – February 27 2008, GTZ, IWMI and the GLOWA Volta Project organized a multi-stakeholder workshop in Accra, Ghana on "Second Ghana Dams Forum and Workshop on the "Impact of Climate Change on the Bui Hydropower Project". The objectives of the workshop were the presentation of GVP research results and a multi-stakeholder dialogue on the impact of climate change on the planned Bui Dam in Ghana. The participating stakeholders were representatives from communities affected by dams, NGOs, government agencies and research institutions. Constanze Leemhuis, Wolfram Laube and Barnabas Amisigo from the GVP chaired the workshop.

From April 1 – April 2 2008 UNU-INRA organized a multi-stakeholder workshop on "Irrigation Options in the changing environment of the White Volta" in collaboration with Water Resources Commission (WRC) and the Ministry of Food and Agriculture (MoFA) in the SSNIT conference room in Bolgatanga, Ghana. The main objective was to share GVP's outputs and scientific tools on climate change adaptation with stakeholders in the Volta Basin. 55 participants attended the workshop.

From May 19 – May 23 2008 UNU-INRA organized a training workshop on "Introduction to Geographic Information Systems and Remote Sensing" at the Center for Geographic Information System and Remote Sensing, University of Ghana, Legon, Ghana. Participants to the training workshops were from partner institutions of the GLOWA Volta project. Invitation letters were sent to these institutions to nominate two staff each to be trained in GIS and RS. The total participants for the training workshop were 15. During the five days training workshop, participants were taken through concepts and application of Geographic Information System and Remote Sensing.

The last workshop which organized by UNU-INRA in 2008 was held at the Africa Wetland Center, University of Ghana, Legon, Ghana on June 26 2008. The workshop was on introducing MIKE BASIN / WEAP. The MIKE-BASIN and WEAP models are used in water resources planning and management. The objective of the workshop was to introduce participants to these water allocation and reservoir operation models. The workshop was a combination of short lectures and demonstrations. The topics and resource presenters were Dr. Barnabas Amisigo (Hydrologic-Economic Model Integration for the Volta Basin), Dr W.E.I. Andah (Introduction to WEAP) and Dr. Wilson Agyare (Introduction to MIKE-BASIN). Participants of the training workshops were from partner institutions of the GLOWA Volta Project. Invitation letter were sent by UNU-INRA to institutions in water resource management in Ghana to nominate staff to participate in the introductory workshop. The total number of participants for the training workshop was 17.

Cluster I: GLOWA Volta Decision Support System

DSS encompass a wide range of scientific simulation tools embodying various methodological approaches and technologies. However, there are several reasons why DSS are not often used effectively at the management level, including lack of user-friendly interfaces, insufficient involvement of potential end-users in software development, poor identification of user needs and lack of adequate system infrastructure. The primary goal of cluster I is to facilitate the development of an effective, user-friendly Grid-based DSS infrastructure for water management in the Volta Basin.

Sub-project I1: Requirements Engineering

In this sub-project, several open source frameworks for building grid applications were identified and tested towards their possible implementation for the GVP DSS infrastructure. It was decided that the Gria 5.1 grid platform will be used. Another subject was the establishment of a data transformation facility within the Gria environment.

Methodology and results:

The research work of M. **El-Gayyar** can be summarized in the following four points:

1. Explore some open-source frameworks for building grid applications: The main goal of this activity was to test and clarify the main capabilities of certain grid frameworks (mainly GRIA and Unicore) and to determine which one is more suitable to our project according to the use cases defined in Sub-project I1
2. Explore some Grid based Workflow engines: The main goal of this step was to be familiar with different currently available scientific workflow engines (mainly Triana, Taverna, and Kepler) and identify its main characteristics, advantages and weakness. The main characteristics taken into consideration during this study were:
    - Workflow structure (DAG, Non-DAG)
    - Workflow model/specification (abstract, concrete)
    - Scheduling architecture (centralized, hierarchical, decentralized)
    - Fault tolerance (on task level and on workflow level)
    - Intermediate data movement (centralized, mediated, P2P)

3. Explore some Workflow languages: Here we focus on different available scientific workflow languages (mainly XScufl, MoML, SWFL and GMDL) to identify its structure and the main differences between these languages. Two main important points was considered:
    - Which workflow patterns are supported by such language?
    - What about the extension capability of such language?
4. Determination of the functional and non-functional requirements of our expected distributed workflow system according to the requirements formulated in Sub-project I1.

According to the determined requirements, he designed a new framework for workflow management and execution in data-intensive grid workflows. Such a framework will be discussed in more detail in the next section. The implementation and evaluation of such a system is now in progress.

Scientific workflows allow users to create a collection of tasks, assemble these tasks into a network of operations on task’s produced data, and execute this network over geographically distributed computation nodes.

Many existing systems already address several fundamental issues for scientific workflows specifications and management, and some have been successfully deployed as a driving tool to orchestrate several applications across various science disciplines. However, there are still many challenges facing the design and implementation of an efficient scientific workflow management environment. The main reasons behind that are the characteristics of scientific applications that are too computationally intensive.

Moreover, such applications generate and reference huge heterogeneous datasets. Regularly, large amounts of data are generated by long running applications and simulation systems. One example is the GLOWA Volta Project launched in May 2000 to support sustainable water resource management in the riparian countries of the Volta Basin in West Africa (1). To help the project’s researchers in the decision making process, scientific workflows are introduced in order to orchestrate and integrate several involved simulation models and heterogeneous data sources. A practical evaluation of the most potentially suitable scientific workflow systems showed that each of them still lacked features to fit the project needs. Therefore, a new approach for scientific workflow management was presented (2).

The new approach (Figure 15) provides means for distributed execution of abstract workflows. The basic idea of this approach is to separate workflow control and execution flows. The proposed approach can be realized as a deployment of a bundle of WSDM services (3) for workflow management in every grid node. Such a bundle of services contains four main services. First, the resource information service, which can be used to retrieve information about resources involving both, relatively static information such as system configuration, and more dynamic information such as instantaneous load.

Second, the scheduler service which coordinates the execution of a workflow instance. It breaks the instance into small tasks, submits each task to a specific grid node, monitors their execution and gathers the final outcome of the submitted workflow. The selection of proper resources is done by contacting the Service Catalog to retrieve for each task a list of currently available resources. This list will be ordered depending on the similarity between the task's resource requirements and the resources' current state. The scheduling of each task is done only after the completion of all its predecessors.

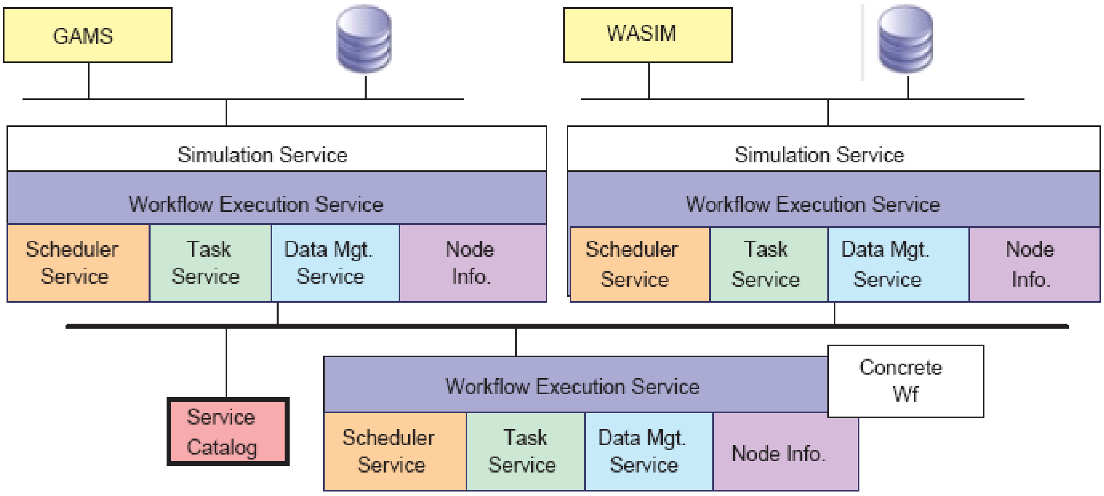

Figure 15: Workflow Management

Source: El-Gayyar 2008

Third, the task service which is responsible for the actual execution of the submitted task, caching the tasks output, and notifying the submitting scheduler about the task status. Finally, the data management service, which is dedicated for reference-based data movement between nodes and data provenance. Here OGSA-DAI service (4) exposes the generated service/application data as web services, which allows direct remote access to the data. The remote interaction of services located in different nodes is based on publish and subscribe notification events supported by the Web Services Notification framework (5).

According to this principle, execution control of workflows remains centralized, but their actual execution is moved to local grid nodes where the data and services are located. Consequently, many advantages can be obtained. First of all, this will avoid unnecessary movements of data through the network. Second, smart rerun can be easily achieved through data caching and provenance mechanism. Last but not least, distributed fault handling and load balancing can be accomplished through the use of scheduler services in different grid nodes.

In 2008, the main research efforts of A. **Savinov** and colleagues were aimed at developing a technological basis for the M^3 model which couples GAMS-based economic model and a hydrologic model based on Mike Basin simulation system. The design criteria for this infrastructure were as follows: The user works with the coupled model using a client which provides means for choosing various scenarios and changing model parameters. The hydrologic model run by the Mike Basin system has to be executed on the server. Each simulation step computes results for one year which are then used to generate parameters for the next step.

After evaluating several systems they have chosen GRIA grid computing infrastructure as the basis for the server where Mike Basis will run. GRIA provides service-oriented infrastructure (SOI) which is designed to support collaborations through service provision across organizational boundaries in a secure, interoperable and flexible manner. The task consisted in adapting this system for the purposes of the M3 integrated model. In particular, it was necessary to install, configure and parameterize this system so that it can be used by the client software. Another task consisted in adapting Mike Basin for work under GRIA. And the third task they were solving consisted in providing data transformation procedures. The problem here is that the GAMS-based economic model and Mike Basin-based hydrologic model use different data formats, and therefore, it is necessary to provide special adapters for converting and transforming data. Essentially, these procedures make it possible for these simulation systems to effectively cooperate within this coupling.

During this period they evaluated GRIA service-oriented grid computing infrastructure and decided that it satisfies main criteria for the M³ integrated model. The system was installed and configured on one of the computers at the University of Bonn. In particular, it was necessary to configure secure access to the system by generating certificates and to configure its job and data services.

The next problem that was solved is installing the Mike Basin simulation system and adapting it for the use from GRIA. The idea was that this originally interactive system could be used in the server model for executing simulation requests sent by the M³ client. Performance of this task required development of a special adapter written on the Python programming language and actively interacting with the COM object representing Mike Basin using special API. This adapter is an integral part of GRIA where it is responsible for starting Mike Basin jobs using parameters received from the client. One important task of this module consists in converting data between formats of GAMS and Mike Basin simulation systems. In particular, input data received in GAMS format have to be converted to Mike Basin and after simulation the results from Mike Basin have to be converted to GAMS format. The final M³ integrated system developed during this period consists of one server where Mike Basin runs under GRIA and the client.

Savinov and colleagues also started working on integrating WEAP hydrology simulation system into M³ model where it has to replace Mike Basin system. However, this direction is currently in the initial phase and will be continued next year.

In 2008, the major research work of Y. **Leng** was to design a system architecture and to test various existing technologies for reducing heterogeneities when integrating with data intensive applications. She has published one paper named “Distributed Scientific Workflow Management for Data Intensive Application” focusing on this work.

After evaluating the use cases of the GLOWA Volta project and existing approaches of data integration, she found that building the scientific workflow is a good way to simplify the process of integration process. However, those updated technologies can not fit our need since they are hard to capture semantic information and is lack of transforming data from one schema to another. Development of a new integration system is hardly needed.

She defined a three layered system: Workflow composition layer, Mapping layer, Semi-concrete Workflow generated layer, workflow execution layer. Her task will be focused on the first three layers. Firstly, the simulation systems are wrapped with SAWSDL which is used to capture semantic knowledge of the underlying simulation systems and then in the Mapping layer, the heterogeneities will be recognized with the help of Ontologies. In the third layer, the correspondent mediators will be generated to do the data transformation.

Sub-project I2: GVDSS Infrastructure

This sub-project developed data management standards and rules of access for the GVP geoportal to improve data quality and security. The demand and needs of local stakeholders were integrated in the definition of rules and a manual for data standards delivered. Other colleagues continued with the development of the DSS tool. The Mike Basin water resources network model serves as a powerful platform to integrate the simulated modeling results of the coupled atmospheric-hydrological model MM5/ WASIM and the economic MATA/ M^3 WATER model.

Methodology and results:

A. **Rogmann** spent part of the first two months of the year writing a documentation handling with the results of two data management surveys conducted with Ghanaian and Burkinabe project stakeholders during two capacity building workshops in 2007 (see annual report 2007).

In May, the first version of the Geoportal was launched as a proof-of-concept for the proposed data information system in the GVP. The development and programming of the Geoportal prototype by J. **Laubach** (Dept. of Computer Science III, Univ. of Bonn), was supported by a survey made with the German GVP project members. This questionnaire has asked explicitly for the acceptance of features provided by the Geoportal prototype. The results were used for the diploma thesis of J. Laubach and for the adjustment of functions to the requirements of the prospective users.

The Geoportal prototype was filled with content by the data management department at ZEF and examined for its usability and user friendliness. The programming of an offline tool to manage metadata locally (without connection to the Geoportal databases) was started by P. **Wittkötter** (scientific assistant) and will be implemented as a module in the Geoportal framework in 2009.

For the GLOWA Volta status conference, demo-scenarios for the Geoportal were developed to promote the flexibility and simplicity of the system in terms of data description, assessment and distribution.

In close co-operation with the senior fellows and their assistants, the second part of the year was used intensively to insert metadata, data and maps into the GVP data infrastructure by using the Geoportal web interface. Seniors and assistants were trained in managing their data using the Geoportal interface.

To prepare the transfer of the GVP data infrastructure to the project partners in the Volta basin, with the Geoportal as main interface node, a two-day workshop in Accra was held at the end of November. The main objective was to introduce the Geoportal and to explore the potentials of the institutional stakeholders to get part of a data exchange network using Geoportal facilities.

The Data Questionnaire report provides an overview of the answers handling with data management issues and mainly given to multiple-choice questions. The core part of this report is a descriptive and graph-based evaluation and problem statement addressing the deficits and demands in relation to data availability respectively, and data exchange by the project partners of the Ghanaian and Burkinabe water sector. Within this documentation, links to database reports (designed with MS Access) and other documents/graphs are included to provide a detailed insight to the results. This document was sent to the participants of the workshops as well as other project members in the Volta basin to increase the awareness in concern to the gaps in local data exchange networks and to tighten up potential stakeholder networks for implementing the GVP Geoportal in 2009.

Thirteen scientist (from senior fellows to PhD students) working in the GLOWA-Volta project have participated in a project-intern survey on Geoportal functionality. Beside of questions dealing with individual data management, several questions were asked in relation to functions for searching, up- and downloading of data and metadata and for visualizing geodata via web-map-services (WMS). The questionnaire had to be answered by observing the running prototype of the Geoportal in the web. Rankings could be given to mark priorities in the range of functions. The main result was that the range of functions provided by the Geoportal predominantly meets the user requirements. Even though this is the case, some modifications in the Geoportal interface were undertaken after the evaluation of the survey.

Due to the fact that internet connectivity is not available at all times or at all locations in developing countries, a Geoportal offline tool was designed and is now under programming. With this tool, the user is enabled to create and to manage metadata on a local machine and upload it through the internet at a later stage. The tool also assists the user in uploading data on the server. User authentication and other database access features are going to be implemented.

A content management system with keyword-lists, a comprehensive metadata editing guide, data categories and thematic maps were included in the Geoportal. Different approaches to transmit information about data and data related knowledge were chosen to exemplify the flexibility of the system.

In June, the integration of data and metadata in the Geoportal began. Through the end of the year, more than 230 metadata sets and 25 different maps (as WMS) were integrated (maps by Peter Wittkötter). Based on an intensive communication between metadata uploader (scientists, assistants) and the data management department, step by step improvements in the Geoportal were achieved.

A Geoportal workshop (26.-27.11.08) with potential members for a geoportal-based information community was organized in Accra and conducted together with Serge **Shumilov**. The main goal was to make the participants familiar with the system, and to explore the demands and potentials of the Geoportal to gain acceptance in the user community. Water management related- and scientific institutions of Ghana sent representatives to this workshop. On the first day, presentations and demonstrations dealing with the Geoportal, its theoretical and technical background as well as its data management framework (user groups, data standards, data policies etc.) were presented and discussed. The demand for a data infrastructure with the Geoportal as main component was broadly stated by the participants. On the second day, participatory exercises were done in relation to institutional data stocks and their restrictions for inter-institutional exchange. In particular, the conditions of owner rights, process status and exchange demands were addressed. A minor part of the data is protected by owner rights and not in the public domain, but the major part has the potential to be shared with other consumers. Efforts have to be made in terms of data quality and preparation for data exchange for a minor part of the described data. In conclusion, the different roles and their requirements within data exchange network based on the Geoportal framework were described (host, metadata and data contributors, data consumers etc.) and the participants were urged to give a statement about their possible position in such a proposed network. The willingness for active contribution of data, respectively metadata, was stated by most of the participants After the workshop the results were inserted into a network diagram using mapping software to back up further implementation steps.

Within an interdisciplinary team of hydrologists, economists and computer scientists (Cluster I) C. **Leemhuis** has been working on the development of a fully coupled hydrological-economic model M³WATER for the Volta Basin. Hereby the MIKE Basin water resources network model (DHI, Kopenhagen) serves as a powerful platform to integrate the simulated modeling results of the coupled atmospheric-hydrological model MM5/WaSiM-ETH and the economic MATA model. The main research activities included the delineation of hydro-economic catchments, development of a climate generator for climate scenario analysis, design of a methodology to include small and medium scale reservoirs of the entire Volta Basin in the hydrological simulation process and the one way coupling of the simulation results of the coupled atmospheric-hydrological model MM5/WaSiM-ETH. The simulation results of the coupled MM5/WaSiM-ETH model serve as water supply input data for the hydrological component of the M³WATER model.

A user interface was developed for the fully coupled M³WATER model to allow users scenario setup and visualization of the results. Furthermore, we successfully tested the ability of the Water Evaluation and Planning System WEAP (Stockholm Environment Institute) to substitute the MIKE Basin network model. We are now in the process of mapping the fully coupled model with the hydrological model WEAP, so we can offer two hydrological versions of the coupled M³ WATER model to the potential user community in the Volta Basin.

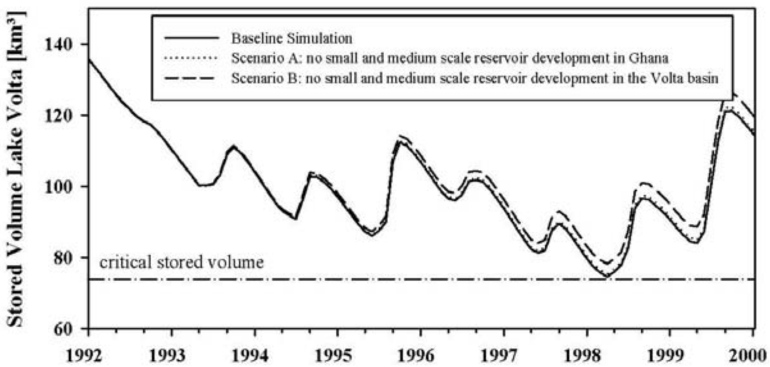

Figure 16: Impact of small and medium scale reservoir development in Burkina Faso on the stored volume of Lake Volta

Source: Leemhuis 2008

The fully coupled hydro-economic model M³WATER is a decision support tool that allows assessing the impact of infrastructure and socio-economic development in the Volta Basin, based on the availability of current and future water resources given through current or future climate conditions. Furthermore, it is possible to test customized climate scenarios for an assessment of the consequences of extreme climate conditions like e.g. a sequence of consecutive dry years. Within a case study analysis the impact of small and medium scale reservoir development in Burkina Faso on the storage of Lake Volta and hence on hydropower generation in Ghana was evaluated under different climatic conditions. For an impact assessment of possible large reservoir development in Burkina Faso, the performance of the two existing large reservoir sites and further potential large reservoir sites in Burkina Faso was simulated with the hydrological component of the M³WATER model and evaluated regarding the water resources of both countries. The results of this case study indicate that the impact of small and medium scale reservoir development in Burkina Faso on the water resources of Ghana is marginal compared to their benefit of securing food production during the dry period (Figure 16). However, climate variability, like a sequence of two dry years, causes severe storage losses of Lake Volta in Ghana (Figure 17). The impact of large reservoir development in Burkina Faso on the reservoir operation in Ghana depends on the degree of a jointly sustainable management of the reservoirs. The hydrological component of the M³WATER model allows quantifying the impact of small, medium and large scale reservoir development on water resources in the Volta basin and the results can be used as an objective communication basis for transboundary water management issues.

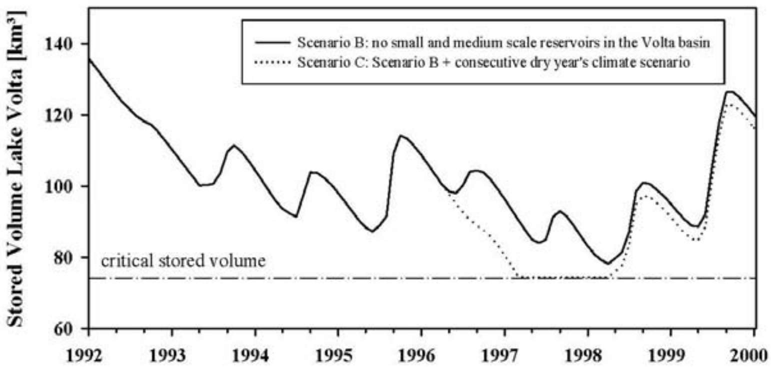

Figure 17: Storage losses of Lake Volta after two consecutive dry years

Source: Leemhuis 2008

Sub-project I3: GVDSS Workbench

This cluster developed the Advanced Visualization Framework, which will allow future users to import and compute data interactively in the form of diagrams or charts. The 2006 prototype was refined.

Methodology and results:

One of the major collaborative achievements of GLOWA Volta Project in 2008 was the development of the hydro-economical model M³WATER for the whole Volta basin. The role of I. **Denisovich** in this activity was the development of the graphical user interface that allows users to simulate complex scenarios without any background knowledge of models running behind. All important model parameters are entered with convenient dialogs. After that, the user simply presses a button to start the integrated simulation, and after it is finished, can browse and analyze the results in a specially a designed visualization interface. This data presentation interface was developed using the analytical visualization framework introduced earlier. The framework itself was greatly improved and adapted to provide functions needed for effective representation of the model output. Its modules for data transformation and aggregation were also used for collection of data produced by hydrological and economical sub-models during their runs. The framework was also extended to support execution of remote tasks in grid infrastructure based on the GRIA system. As easily as building local data transformations with traditional AVF modules, the user can now attach grid jobs running on remote machines. New modules provide services for discovery of available grid services, submitting grid jobs and transfer of data between local client and remote grid node, as well as directly between grid nodes.

The M³WATER model combines the hydrological model in Mike Basin with economical model in GAMS. Simulation is done in one year cycles. Yearly water demand provided by GAMS needs to be transferred into Mike Basin, which, in turn, generates yearly water supply needed by GAMS. Models exchange data until the optimization shows no further significant change. After that, simulation proceeds to the next year. The automation of model execution is done by the M³WATER client. It is responsible for providing models with input data, running them, getting simulation results, adapting data to be passed to another model, as well as collecting and aggregating yearly results for the common output of the simulation. Hydrological models need rainfall data for the period of simulation. The user can classify each year of the simulation into five categories as very wet, wet, regular, dry or very dry. Based on this selection, the client takes the real rainfall data of a characteristic year from the past and feeds this data to the hydrological model. Since Mike Basin needs a special computer with a hardware protection key to run, it was decided to provide this infrastructure for the common use and organize access to this computer using grid technology. The GAMS model is more tolerable to the environment, and for the first version of the integrated model it was placed directly on the client computer where the main client interface is also located. In later development, the GAMS model was moved to a grid node. Because of such distributed architecture of the M³WATER model, it was the task of the client software to bind all modules together, provide transparent access to local and remote models, prepare and transfer all required data and simulation parameters to the models and monitor their execution. After the simulation is finished, the graphical analysis tool based on AVF is started, where the user can browse aggregated results in form of tables and diagrams.

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