The WAVES Program: Conception, Results and Perspectives

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Abstract

The Northeast of Brazil is characterized by recurrent drought spells causing severe environmental damages, high rates of migration and low quality of life. Many indicators of climate global change occur significantly pronounced in this region. Besides this, a drastic decrease of precipitation within the next 50 years has been predicted for this region.

In 1994, the WAVES Program began through contacts between scientists with interest in interactions between water resources and socio-economics in the Northeast of Brazil. As a result of the joint work, the framework document, approved in October 1995, has been regarded as a guide to define all subsequent actions related to the WAVES program. The main objective of the WAVES program is gathering Brazilian and German scientists from different disciplines focusing on the states of Ceará and Piauí in order to understand the interactions between water availability, ecosystems and human systems. It aims to build up integrated models as an additional tool to develop sustainable strategies to make semi-arid regions less vulnerable to climatic changes.

In order to study the very complex environment, it was necessary to compose the following multidisciplinary groups: Water Resources, Agroecosystems, Climate, Socio-Economics, Landscape Ecology and Integrated Modeling. As effective results, it can be mentioned (1) Forming and strengthening of new research groups in both Brazilian and German institutions; (2) Training and qualification of personnel in areas of knowledge, that were deficient concerning the existence of qualified people. The lack of expertise is a serious obstacle for developing a scientific basis for sustainable development; (3) Establishing tools and methods for the integration of scientific knowledge.Within a relatively short period of three years of interdiciplinary, bilateral research, prototype versions of two models integrating and coupling climatic, hydrological, agricultural and socio-economic aspects at different scales have been developed: (i)The mesoscale model MOSDEL (**MO**del for **S**ustainable **DE**velopment of **L**and use and Water Resources) and (ii) the macroscale model SIM (**S**emi-arid **I**ntegrated **M**odel). Pioneer work has been carried out in the area of integrated research at a regional scale involving the concise definition of disciplinary interfaces and the development of scaling procedures. There is now a need of intensive, time and labour consuming calibration and validation of these two models with their respective submodules. Another important benefit of the WAVES program is the strengthening and developing of universities and research institutes in the Northeast of Brazil.

As the WAVES program develops, it is expected to generate scientific knowledge to provide support for new tools of intervention aiming to preserve natural resources and to improve the living conditions in semi-arid regions. The successful validation and implementation of the integrated models would be a tremendous progress in the area of integrated research and regional modeling. In this case, the methods and knowledge should be transfered to other regions and to research programs that deal with the sustainable development of natural resources.

Keywords: Northeast Brazil, WAVES, conception, organisation, integrated regional models, scaling

1 Introduction

As a result of the worldwide increase of utilization of fossil energy sources, changes in the global climate occurred because of the rise of concentration of greenhouse gases in the atmosphere. The global climatic change will affect in particular semi-arid regions. These areas cover one third of the earth, and they have about 20% of its population. The rise in mean temperature will cause degradation of natural resources and human living conditions through prolonged drought and decrease in water availability. Thus, it is necessary to assess the interactions between climate change, the geosphere, the hydrological cycle, the biosphere, and above all, the impact on the quality of human life. It was with this concept of multidisciplinary and integrated approach that the WAVES Program was conceived.

2 Conception and objectives of the WAVES program

In 1994, the WAVES Program began through contacts between scientists with interest in interactions between water resources and socio-economics in the Northeast of Brazil. By that time, the identification of qualified personnel and appropriate infrastructure was important for conducting high-quality research in cooperation with German counterparts which resulted in a broader approach of the program. Thus, the involved researchers contacted CNPq and DLR, which decided to elaborate a program with a holistic and imperatively integrated approach to study interactions between climate change and variability, water availability, as well as sensitive ecosystems and society in the NE of Brazil. The Northeast of Brazil was selected because many indicators of climate global change occur significantly pronounced in this region (Figure 1). For many years, recurrent drought spells have caused severe environmental damages and high rates of migration, causing low quality of life. Besides this, a drastic decrease of precipitation within the next 50 years has been predicted for this region.

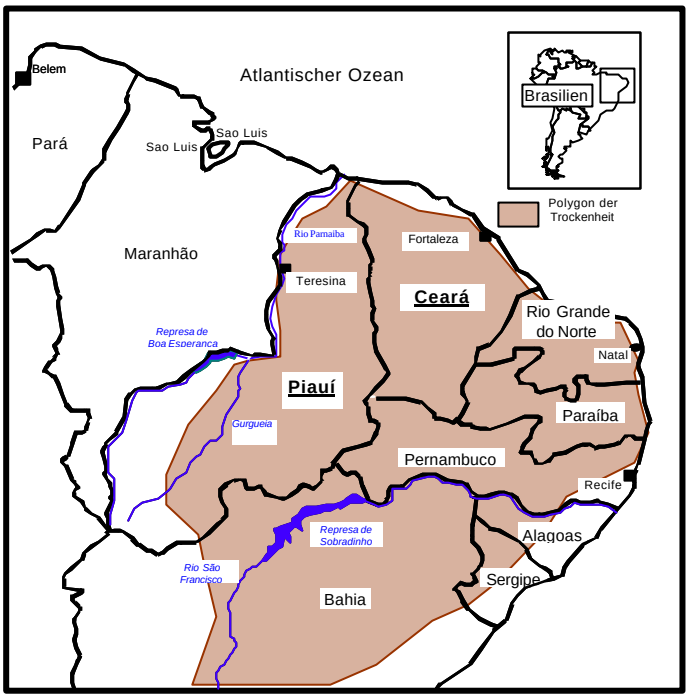

Figure 1: The study area of the WAVES program extends over a land surface of approximately 400.000 km^2, covering the states of Ceará and Piauí

Since the beginning, it was important to have a close interaction and exchange of ideas between Brazilian and German partners. The first official meeting was held in Potsdam, in March 1995, establishing the first draft of the framework concept, as a clear indication of common goals and scientific ideas. Although sometimes different opinions appeared, it is important to emphasize the spirit of understanding among researchers and administrators all along the development of the WAVES program. As a result of the joint work, the framework document that was approved in October 1995 has been regarded as a guide to define all subsequent actions related to the WAVES program.

The main objective of the WAVES program is gathering Brazilian and German scientists from different disciplines focusing on the states of Ceará and Piauí in order to understand the interactions between water availability, ecosystems and human systems. It aims to build up integrated models as an additional tool to develop sustainable strategies to make semi-arid regions less vulnerable to climatic changes.

3 Project structure

The organizational structure is outlined in figure 2. A German-Brazilian Mixed Steering Committee is in charge of the scientific supervision of the program with respect to research objectives and methodology. It gives

scientific direction and approves the program framework. The Steering Committee is formed by governmental representatives and independents scientists will be called by the funding agencies of the respective country.

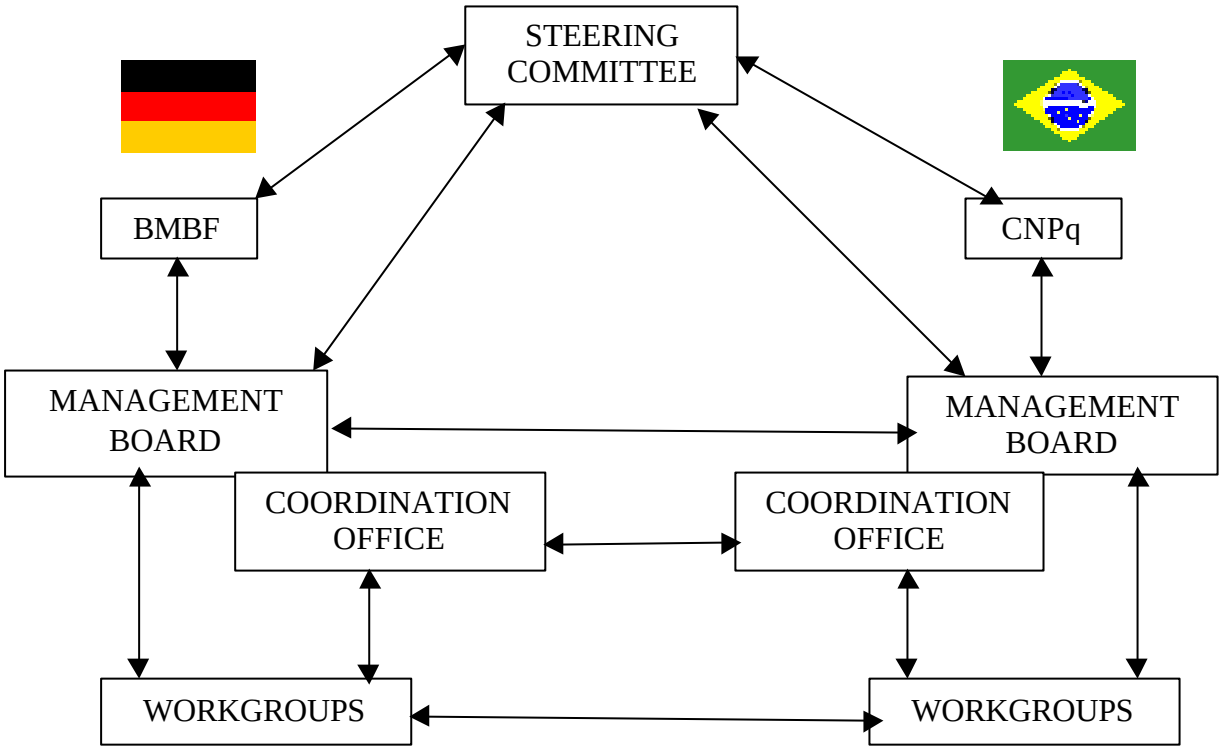

Figure 2: Organizational structure of the WAVES program

The German-Brazilian Management Board is to follow up and control the research activities in the two countries. It has to guide and harmonize the work concerning to the objectives of the program. The Management Board takes decisions in agreement with the program framework aproved by the Steering Committee. Working group proposals jointly prepared by Brazilian and German Scientists are submitted to the Steering Committee or the Management Board, which have to monitor the adherence of working group proposals to the general goals and concept of the project. The Management Board consists of responsible scientists of the project (5 scientists of each country) and should cover the whole disciplinary range. The Management Board meets at least once a year.

In order to execute the coordinative tasks within the project, the Management Board will be assisted by the Project Secretariat. In each country, the Project Secretariat is responsible for the information flow between the Steering Committee, the Management Board, and the working groups. It is also responsible for the contact to the project secretariat of the other country.

In order to study a very complex environment, it was necessary to compose the following multidisciplinary groups: Water Resources, Agroecosystems, Climate, Socio-Economics, Landscape Ecology and Integrated Modeling. Figure 3 shows the integration of the 6 research groups.

The Water Resources research group has the following objectives:

- Hydrological modeling of the States of Ceará and Piauí (HYMO/NoWUM) and the Rio Guaribas Bassin (WARIG) (Güntner and Bronstert, 1999, Hauschild and Döll, 1999, Heinrichs et al. 2000)
- Water management decision support system.
- Assessment of erosion and sedimentation in reservoirs.
- Evaluation of water costs (capital investment, operation and maintenance of the systems).
- Assessment of water quantity, quality and distribution.
- Quantification of salinization of ground and surface water.
- Determination of sources of salt and mechanisms of salinization.

- Functioning of the fractured crystalline rock aquifer in Ceará
- Statistical evaluation of the reliability of dams in a scenario of changing climate.

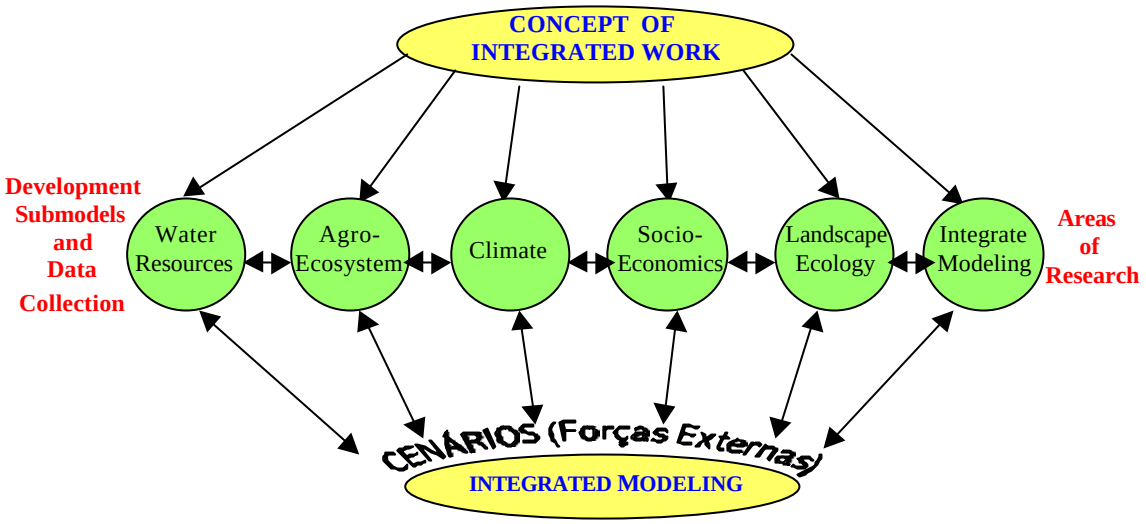

Figure 3: Integration of working groups

The Agroecosystem research group aims to:

- Calibrate and validate mathematical crop models of the 13 most important crops in Piauí and Ceará by using EPIC, ALMANAC and CROPWAT (Gaiser and Hilger 1997, Hilger et al. 2000)
- Assess the constraints, limitations and environmental impacts on crop production systems currently in use.
- Develop a Soil and Land Resource Information System for Piauí and Ceará (SPICE) for extrapolation of simulation results to the state level. (Gaiser et al. 2000)
- Describe economically and ecologically sound crop production systems for the target area.
- Evaluate crop yields under actual conditions of climate and soil.
- Define stability of crop production systems under specific climate conditions.
- Potential changes of crop yields in function of future climate variations.
- Identification of limiting factors in plant and animal production.

The Climate Research group has as main objectives:

- Spatial and temporal structures of different meteorological and hydrological parameters on the basis of observed and modeled values (precipitation, temperature, humidity).
- Improvement of the description of the future climate development using scenario models.
- Spatial and temporal development of extreme events.
- Obtain primary and secondary climatic data of the Northeast of Brazil and make them available to all groups of research.
- Elaborate climatic models to create scenarios in function of global warming.
- Validate regional climatic models to provide support for sustainable development in the Semi-arid Region of Northeast of Brazil.

Concerning the Socio-Economic research group, it is expected to:

- Evaluate subjective factors applied by the rural population concerning the definition of life quality.
- Establish relations between environmental changes, life quality and human behavior.
- Identify socio-economic characteristics of farms.
- Development of the **R**egional **A**gricultural **S**ector **MO**del (RASMO, Hinterhür and Gaese, 1999) to provide assistance to sustainable development programs for both focus regions (Tauá and Picos) and states (Ceará and Piauí).
- Verification and validation of the life quality/migration model MigFlow taking actual data into account.
- Development and evaluation of intervention scenarios analysing improvement of living conditions of the rural population.

The Landscape Ecology research group concentrates on:

- Large scale analysis of remote sensing data for the complete area of the states of Ceará and Piauí.
- Characterization of land cover at meso-scale by functional vegetation units (FVU) to support the water balance models and to assess the relationship between vegetation, development and land use under changing climate conditions (input to MOSDEL).
- Development of the mesoscale model MOSDEL for the focus regions Tauá (CE) and Picos (PI).
- Identification of the geo-environmental potential of landscape units.
- Analysing the availability and quality of water at a long range, occurrence of erosion and the utilization of areas ecologically adapted.
- Large scale determination of temporal development of vegetation during dry and rainy years.

As a result of its conception, the Integrate Modeling research group plays a major role and aims to:
- Provide an interdisciplinary dynamic and quantitative representation of the natural-societal system.
- Describe the relations between water availability and social processes (specifically migration), under high variable climatic conditions at the meso- and macroscale.
- Generate practical reasoning modeling under imprecise or incomplete knowledge applied to the management of water resources.
- Analyse the migration problem in integrated modeling using symbolic computation coordinators.
- Carry on the parallelization of algorithms applied to the optimization of large systems.
- Elaborate digital terrain modeling applied to location and management of water reservoirs and to the study of environmental impacts.
- Analyse long term development options for the region in scenario studies in a global change context.

4 Expected benefits

Important benefits are expected from the WAVES Program at different levels:

1) at the political level (planning institutions)
- To help regional planners and political decision “makers” to select strategic solutions for the Semi-arid Northeast of Brazil.
- To assess economic and social consequences of their decisions under changing natural and socio-economic-conditions.

2) at the disciplinary level
- Improvement of the weather forecast for the Northeast Region of Brazil (FUNCEME).
- Amelioration of forecast about filling stage of water reservoirs, flooding and preventive management of water resources.
- Optimize the agricultural production under careful management of natural resources and forecast of economically important crop yields (EPIC).
- Innovative approach for decisions in the agricultural sector of credit business.
- Evaluate the efficiency of application of national and international funds through social-economic indicators of life quality.

3) to the scientific communities in Brazil and Germany
- Consolidation of research groups and formation of innovative ones.
- Coordination, moderation and integration of different research areas and international workgroups at various scales.
- Human capacity building (Undergraduate and Graduate Programs)
- Carry on research based on mathematical mechanistic models that allow effective extrapolation to other regions of the world.
- Development of new expertise concerning understanding and planning of sustainable development programs in a semi-arid regions under climate change.

Since 1995, the program has gradually evolved from the basic conception to an integrated and effective program. The basis for the success were common objectives and the personal commitment of scientists in Germany and Brazil. Then, the endorsement and support by the funding agencies CNPq and BMBF enabled WAVES to become a structured and effectively operating research program. As effective results, it can be mentioned (1) Forming and strengthening of new research groups in both Brazilian and German institutions; (2) Training and qualification of personnel in areas of knowledge, that were deficient concerning the existence of qualified

people. The lack of expertise is a serious obstacle for developing a scientific basis for sustainable development; (3) Establishing tools and methods for the integration of scientific knowledge.

5 First results

Within the relatively short period of three years of interdiciplinary, bilateral research, prototype versions of two integrated models for different scales have been developed:

- The mesoscale model MOSDEL (**MO**del for **S**ustainable **DE**velopment of **L**and use and Water Resources)
- The macroscale model SIM (**S**emi-arid **I**ntegrated **M**odel)

5.1 The mesoscale model MOSDEL

The mesoscale model MOSDEL is a GIS based model software that integrates the results of the research groups working in the focus region Picos (Voerkelius et al. 2000). The specific problem of the Picos region is a conflict between use of fossile groundwater for human consumption and for irrigation. The risk of the depletion of the drinking water reserves through irrigation has to be assessed and alternative strategies for land use and water supply to the irrigated area have to be developed. The Picos region is dominated by the Rio Guaribas watershed that is controlled by the "Guaribas Bassin Comittee". The objective of the research efforts is to develop a decision support system (DSS) for the sustainable water management of the Rio Guaribas Watershed through the local water authorities.

MOSDELis designed to constitute the scientific basis of a Decision Support System. The extent of the model comprises an area of approximately 3000 km^2 and includes the major part of the Rio Guaribas Bassin. The spatial resolution of the model is 0.01 km^2 . The input parameters characterize the ecological conditions (rainfall, soil, terrain, water availability), land management (farm type, crop rotation, crop management, land and capital availability), population dynamics and market conditions (Figure 4). The input data are processed in various submodules (hydrological models for surface and groundwater, agroecological model for crop yield calculation etc.) and the results are spatially integrated in different GIS layers (Figure 5).

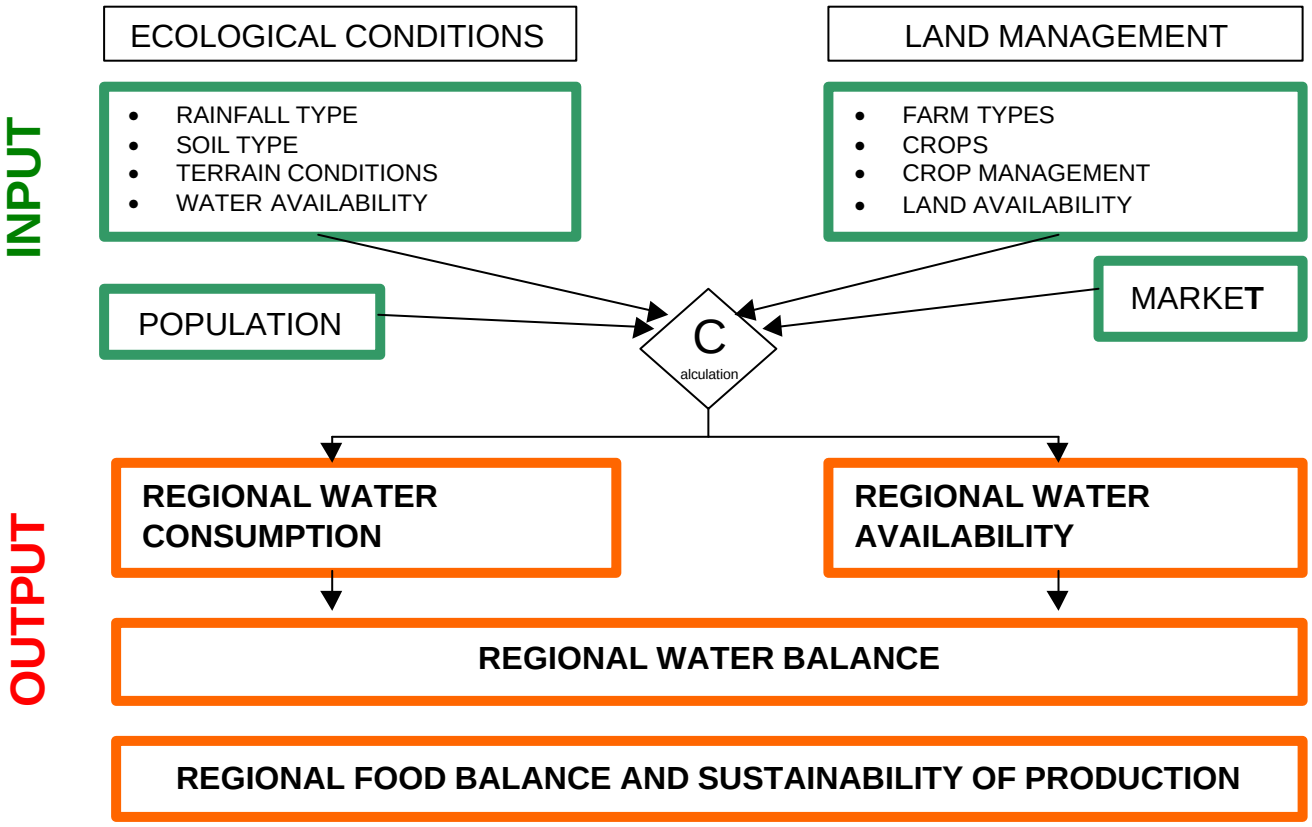

Figure 4: Structure of the mesoscale model MOSDEL

The model output provides information about the regional water balance, estimates about the regional food balance, indices for the sustainability of land use including the economic situation of different farm types on an annual basis. In Figure 6, the effect of two different situations with respect to amount and distribution of rainfall on the regional water balance is shown. Under the weather conditions of an extreme dry year (1942/43) with a total amount of 410 mm, almost the total precipitation was consumed by evapotraspiration and only a small part of 5% (23 mm) contributed as run-off to the recharge of the rivers and dams. On the other hand, under the conditions of a relatively wet year, there is much more run-off in relative (12% of rainfall) and absolute (83mm) terms. Although the weather situation in the reference year 1996 was moderate to good (717 mm), the economic situation of the farms that are relying on rainfed agriculture was not satisfactory (Figure 7). The mean income per person was below the minimum salary of approximately 2 R$ per day. The same was true for farming systems with irrigation, except for the highly intensive horticultural production systems in the municipality of Picos with close distances to the local market. The model must now be calibrated and validated with the data available from census years.

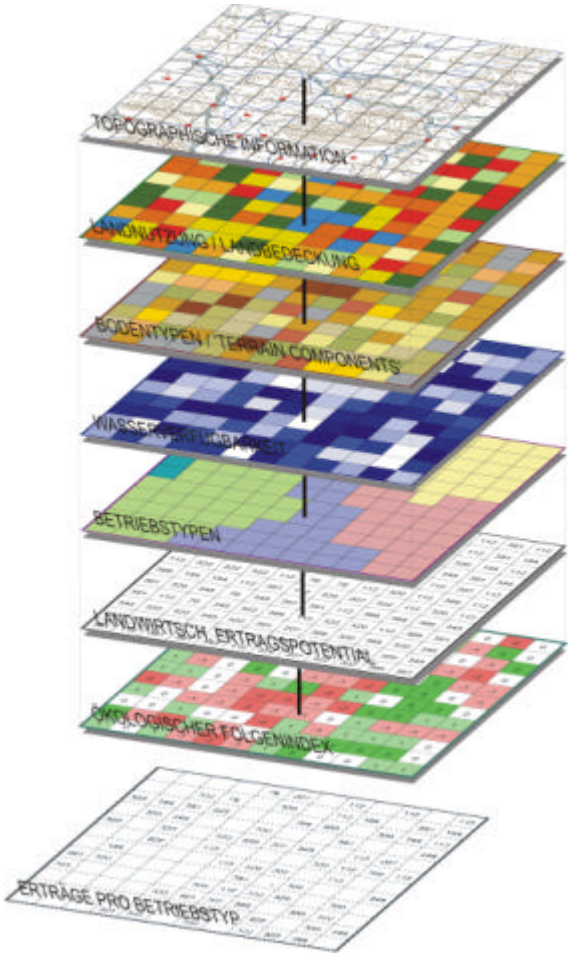

Figure 5: Spatial integration of the data layers by MOSDEL

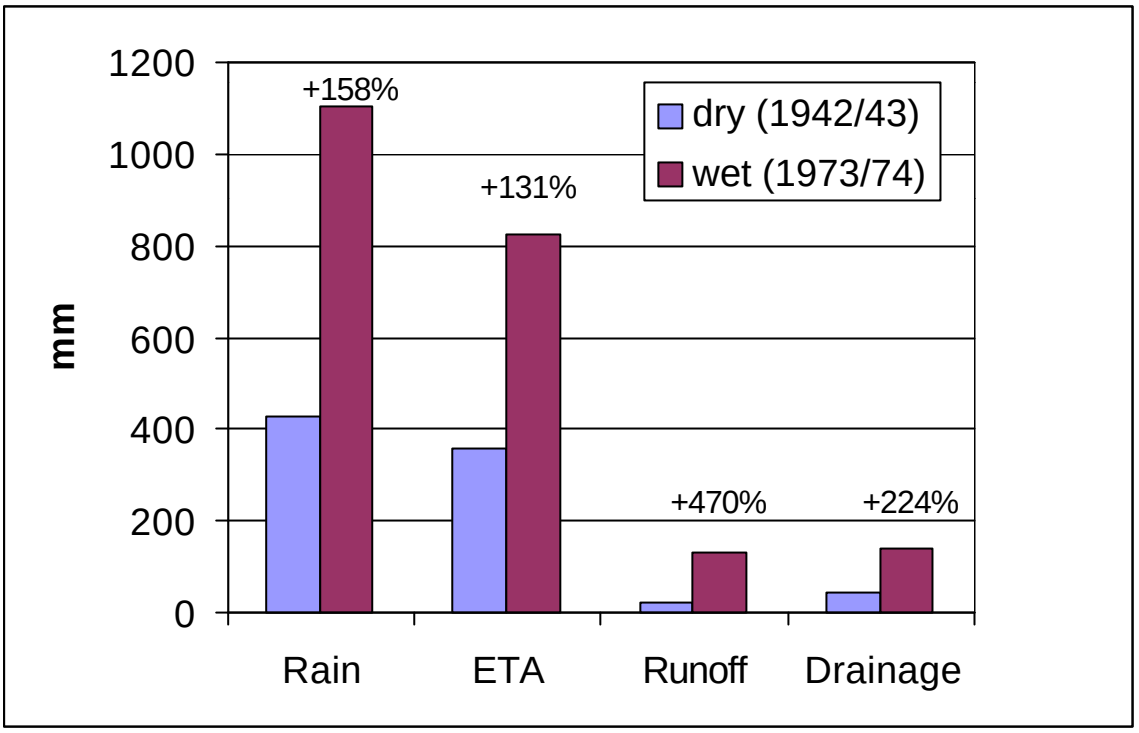

Figure 6: Regional soil water balance in the Picos region in a dry year and a wet year

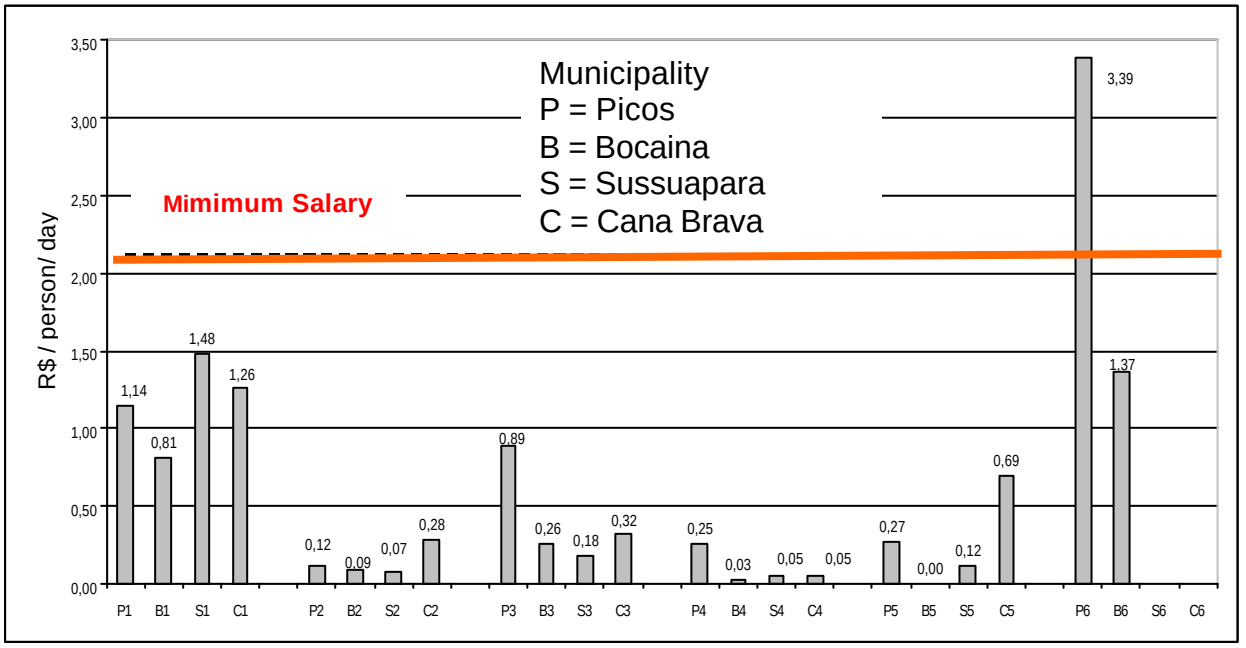

Figure 7: Mean income of different farm types in relation to their ecological conditions (1,2 = Chapada; 3 = Chapada / Baixio; 4, 5, 6 = Valley) and the farming system (1,4 = market oriented; 2,3 = subsistence; 6 = horticulture)

5.2 The macroscale model SIM

In contrast to the mesoscale model MOSDEL, the **S**emiarid **I**ntegrated **M**odel SIM (Bronstert et al. 2000) covers the entire area of the states of Ceará and Piauí (ca. 400.000 km^2). Both states are characterized by limited and highly variable water availability and steadily increasing water demand through population growth, irrigated agriculture and industry. In addition, climate scenarios predict a very probable decrease of the precipitation within the first half of this century., particularly in the South of Ceará and in the East of Piauí. The objective of the creation of SIM is therefore to provide a scientifically sound basis for regional planning institutions in order to identify possible strategies for the sustainable development of water resources in the states of Ceará and Piauí. In general, the resolution of SIM is the municipality. However, since SIM is a modular system, most of the submodels work with a much higher spatial resolution, like the large-scale hydrological model (HYMO) or the soil and land resource information system (SPICE) (Figure 8). On the other hand, the climate scenarios are derived from global circulation models and considerable effort was necessary for downscaling the results to the level of the municipalities. This shows that up- and downscaling procedures are of high relevance for the functioning of SIM and pioneer work has been carried out in developing the model.

Another focus of the WAVES program in connection with the development of integrated models is the construction of possible future developments in the states of Piauí and Ceará (scenarios). Intensive interdisciplinary meetings and discussions were held to learn and get acquainted with different scenario techniques. Two main stream scenarios were elaborated which correspond to different actual trends in the global economy: globalization and decentralization (Doell et al. 2000). Preliminary results concerning climate scenarios for the coming five decades abd the respective model output were presented at the workshop (Jäger et al. 2000).

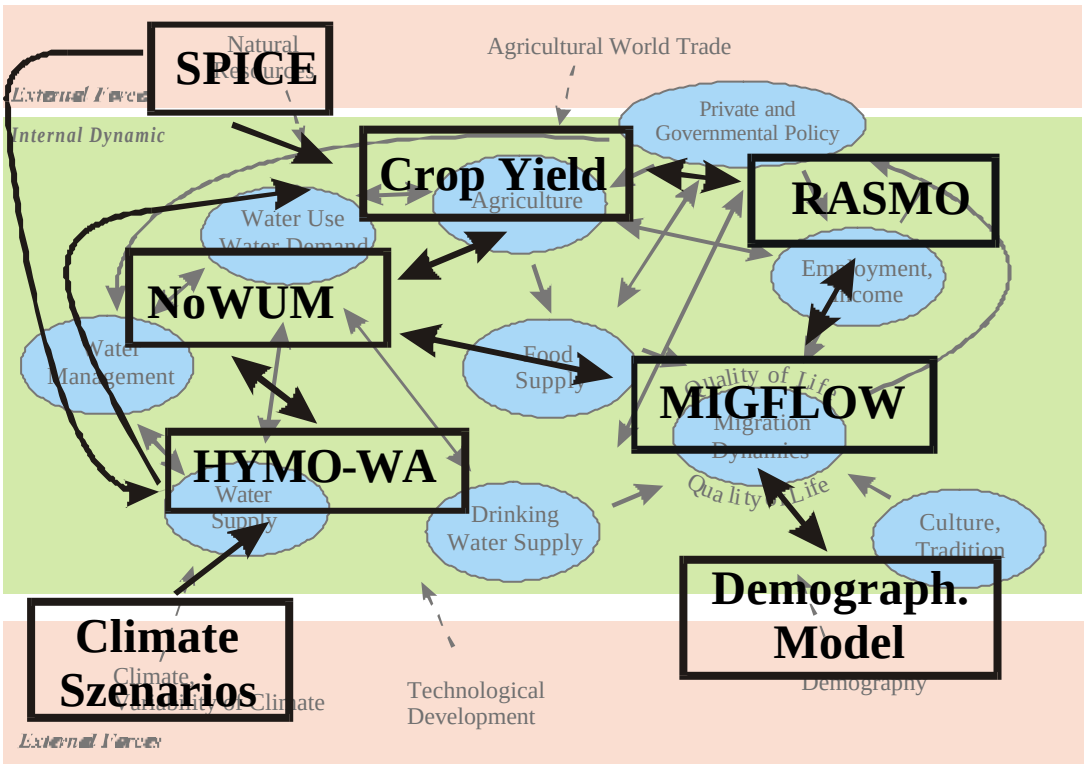

Figure 8: Modular structure of the Semi-arid integrated model SIM

6 Publications and capacity building

Since 1997, the number of publications by WAVES scientists increased from 10 in 1997 to 47 in 1999. Although the proportion of congress papers is higher, there are considerable efforts to publish in reviewed books and journals. At the same time, there is an increasing number of master and doctorate students involved in the program. Presently, 10 M.Sc. and 7 Ph.D. thesises are in preparation, which will strengthen the academic capacities in the Northeast of Brazil.

7 Conclusions

After a period of conceptual preparation and organizational adjustment from 1995 to 1997, WAVES has started to run effectively as an interdisciplinary, bilateral research program in 1998. Through the personal commitment of scientists in Germany and Brazil, pioneer work has been carried out in the area of integrated research at a regional scale involving the definition of disciplinary interfaces and the development of scaling procedures. Prototype versions of two integrated models at different scales, integrating and coupling climatic, hydrological, agricultural and socio-economic aspects were established. There is now a need of intensive, time and labour consuming calibration and validation of these two models with their respective submodules. This requires the cooperation with state and national authorities which dispose of the necessary data and are, at the same time, potential users of the models. Additional information about the spatial distribution of land use, the water quality and socio-economic aspects at the macroscale will be necessary. Another important benefit of the WAVES program is the strengthening and developing of universities and research institutes in the Northeast of Brazil, which is in line with the special program for capacity building promoted by CNPq.

As the WAVES program develops, it is expected to generate scientific knowledge to provide support for new tools of intervention aiming to preserve natural resources and to improve the living conditions in semi-arid regions. The successful validation and implementation of the integrated models would be a tremendous progress in the area of integrated research and regional modeling. In this case, the methods and knowledge should be transfered to other regions and to research programs that deal with the sustainable development of natural resources.

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