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WAVES

WATER AVAILABILITY, VULNERABILITY OF ECOSYSTEMS AND SOCIETY IN NORTH-EAST BRAZIL

Regional-scale water use modeling and scenario development for two federal states in Northeastern Brazil (Piauí and Ceará)

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Project leaders:	Dr. Petra Döll and Prof. Dr. Joseph Alcamo

Project number:	01 LK 9705
Project title:	Modellierung von Wasserbedarf und Wasserversorgung als Grundlage des Wassermanagements in Piauí und Ceará im Verbundprojekt WAVES
Period:	1 September 1997 – 31 October 2001

Researchers:	Dipl. Geoökol. Maike Hauschild Dr. Eduardo Mario Mendiondo

Date:	31 October 2001

1 TASKS AND GOALS

The main tasks and goals of the project “Modeling of water demand and technical water supply for water management in Piauí and Ceará” were, according to the research proposal,

1. to collect and integrate knowledge and data of water demand and water management in both federal states, in particular in relation to ecological and socioeconomic conditions.
2. to set up a water balance model that simulates the present and future water demand and technical water supply in the whole of Piauí and Ceará (as submodule of the integrated model of the WAVES[1] program it will allow the modeling of water management), and
3. in cooperation with other subprojects, to develop water management scenarios which, being used in the integrated model, will indicate sustainable developments paths.

On the basis of the experiences and knowledge acquired during the investigations, the tasks and goals were refined but the initial goals remained valid. For the last year of the four-year research period, the goal was to interact with interested Brazilian planning agencies in order to make the research results, in particular the integrated regional scenarios more policy relevant. One particular goal was to couple information on bulk water costs that have been acquired by a Brazilian WAVES working group (leader: Jose Carlos de Araújo) with the water demand (or use) estimates of water use model developed by our WAVES project such that the cost related to the future increase in water demand could be assessed.

2 CONDITIONS

The project was a part of the German WAVES program. An aim of the WAVES program (http://www.usf.uni-kassel.de/waves) was to identify sustainable development paths for Ceará and Piauí, two states in the semi-arid Northeast of Brazil (Fig. 1). The research in WAVES focussed on the interrelation between climate variability, water availability, agriculture and quality of life, and it was geared towards supporting regional planning in the study area. Within the interdisciplinary program, the integrated models (one at the regional scale and one one at the municipality scale) and scenario development served as integration tools. The scenarios, which were supposed to be quantified by the disciplinary models and the integrated models, have been regarded to be an appropriate method for supporting sustainability-oriented research and regional planning.

At the start of the project, it was possible to build on the research done by other research groups during the pre-phase of WAVES (in which our group did not participate). However, this was only possible to a small extent as the groups that participated in the pre-phase were

[1] for a list of abbreviations, see Appendix 1

not concerned with a quantitative estimation of water use or scenario development. Water use modeling was possible only with the help of climate data supplied by WAVES participants from the Potsdam Institute for Climate Impact Research and in cooperation with our Brazilian colleague Jose Carlos Araújo (Water Resources Department, Federal University of Ceará). The development of integrated scenarios required the intensive cooperation of various German colleagues in the WAVES scenario group.

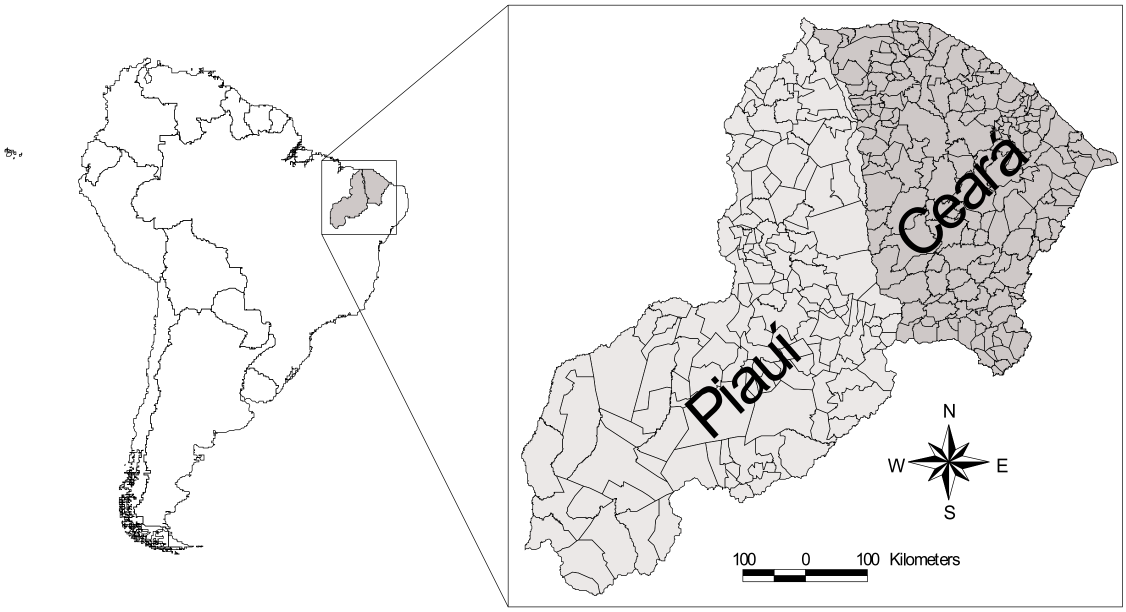

Fig. 1. The study area, the two semi-arid federal states Piauí and Ceará in Northeastern Brazil. The outlines of the 332 municipalities, which are basic computational units of all regional-scale models developed in the WAVES program, are shown.

3 PROJECT PLANNING AND PROGRESS

The research work was planned to consist of the following parts:

- Literature review of water use modeling
- Collection of secondary data in Brazil
- Development of conceptual model
- Model programming
- Computation of present-day water use situation
- Model testing
- Scenario development
- Computation of scenarios of future water use
- Coupling of water cost data and modeled water use
- Interaction with policy makers

With respect to the timing of the above tasks, it is important to note that it took more time than expected to collect secondary data on water use and related data in Piauí and Ceará, which is partly due to the lack of centralized data archiving. Besides, some important data are non-existant, and the quality of some of the data is low (e.g. irrigated areas and crops), which made it necessary to adapt the modeling concept and spend more time on “improving the data” by asking for expert guesses. The collection of secondary data required altogether approximately eight months of stay in Ceará and Piauí, while the interaction with policy makers (mainly in the form of policy workshops) required approximately two months in Brazil. However, the time during these stays was also used for intensive cooperation with our Brazilian WAVES partners.

The first version of the developed water use model was made available for inclusion in the regional-scale integrated model SIM at the beginnning of 1999. The final version, including the driving forces and parameters for the two reference scenarios, was delivered in spring 2001.

The Scenario Group of the WAVES program was initiated (by our working group) in November 1998 and met at regular intervals until May 2001. The first comprehensive water use scenarios were ready by spring 2000 and where refined mainly based on the policy workshops in Fortaleza in November 2000 and March 2001. During the last policy workshop, which took place in June 2001, the integrated regional scenarios and intervention impacts were presented to the policy makers, and strategies to enable the further use of the modeling tools and scenarios in regional planning were devised.

4 STATE OF RESEARCH AT THE START OF THE PROJECT

At the beginning of project, there was not any available water use model that could be applied for the study region. Water management models generally model only river discharge or reservoir management, but take water use as an external input. Therefore, we developed the regional-scale water use model NoWUM.

There were some estimates of water use for the study area, but they were 1) very coarse in their spatial resolution, 2) not well funded (e.g. they use average per capita household water use values and average per hectare irrigation water use), and 3) not always transparent. The impact of global change (including climate change) on water resources issues had not been analyzed before for the study area.

With respect to scenario development, within the group there was only very restricted experience with the scenario methodology but more experience in interdisciplinary work. The scenario methodology was adapted from the approach taken be the Intergovernmental Panel on Climate Change to derive greenhouse gas emission scenarios.

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5 COOPERATION

Throughout the project period, we cooperated with Brazilian institutions in Piauí and Ceará, with Brazilian researchers and with German researchers of WAVES Program.

5.1 Cooperation with Brazilian institutions

There is a rather long list of institutions from which we obtained data[2]: AGESPISA, DHME, FIEPI, FUNASA, PIEMTUR and SEMAR in Piauí, and CAGECEC, COGERH, DNOCS, FNS, IPLANCE, SDU, SEAGRI, SEPLAN, SETUR, SOHIDRA and SRH in Ceará. Besides, we had fruitful contacts with SISAR, a project sponsored by the German Kreditanstalt für Wiederaufbau, a project which organizes water user associations that are responsible for decentralized safe water supply in rural communities. AGESPISA and CAGECE, the two state water supply companies as well as SEMAR and SEPLAN, the state ministries concerned with water issues, and their respective technical instituions, were repeatedly informed about the research approach and results of our project. Starting November 2000, three policy workshops at SEPLAN were co-organized by our group together with other WAVES researchers in order to make the scenario development within WAVES more policy relevant. At the final workshop in June 2001, a strategy for knowledge transfer and application of WAVES results in the context of water and land resources planning in Ceará was developed together with the ministry of planning of Ceará, Dr. Moncia Clark (head of SEPLAN).

At the final presentation of our water use scenarios at SEMAR, SEMAR showed strong interest in further cooperation and expressed their wish to use and extend our water use scenarios for Piauí. SEMAR hopes to optimize water management in Piauí based on the scenarios of water until 2025, which were developed in our project.

[2] for a list of abbreviations, see Appendix 1

In a letter (see Appendix 2), SEMAR proposed in 2001 to contribute in this transfer co-operation with:

1. Official support to CESR-GhK's water-use scenarios in Piauí until 2025
2. Organization of a dialogue agenda between CESR-GhK and stakeholders
3. Participation of CESR-GhK in discussions on regional impacts and climate change
4. Interest of policy makers to use CESR-GhK's results for drought management
5. Grant support to CESR-GhK's researcher who helps in transfer co-operation

Furthermore, SEMAR has requested CESR-GhK that Dr. E. M. Mendiondo visit SEMAR in order to discuss details of that transfer co-operation initiative. CESR-GhK also agreed with this cooperation initiative.

5.2 Cooperation with Brazilian researchers

Our main research partner in Brazil was Prof. Jose Carlos de Araújo and his group at UFC, Fortaleza. Due to his in-depth knowledge of the water situation in Ceará, in particular with respect to irrigation projects and sources of water supply helped us to estimate important parameters in our model. Besides, we discussed with him the storylines of the WAVES scenarios and the resulting water use scenarios, in particular. We integrated results from his working group with respect to the costs of bulk water with our water use scenarios to estimate the cost of the future water supply extension (see section 5.3). In addition, we provided time series of water use between 2001 and 2025 such that Prof. de Araújo could implement a modeling approach leading to a prioritization of future dam construction in Ceará, which is based on water stress scenarios. In this context, our group is participating in the preparation of the joint paper "Water scarcity and management in Brazilian Semi-Arid: Scenarios of global change, authored by Prof. de Araújo (UFC, Brazil), Dr. P. Döll and Dr. E. M. Mendiondo, and Dr. M. Krol and A. Güntner (PIK-Potsdam).

We intend to continue our research cooperation with Prof. de Araújo (compare letter of intent in Appendix 3), in particular with respect to integrated water management under semi-arid conditions in the research areas of water-use modeling, uncertainty analysis, water management under conditions of uncertainty, scenario development, multi-criteria analysis and multi-objective optimization, and large-scale modeling of water quality).

5.3 Cooperation with German researchers

Within the German participants of the WAVES Program, cooperation was most intense within the working group Water (consisting of A. Bronstert and A. Güntner from PIK and of various colleagues at Hydroisotop GmbH) and with the Integrated modeling group (M. Krol and A. Jaeger at PIK). The cooperation consisted, among other things, in exchange of data (climate, water use) and discussions about water scarcity indicators and water allocation, with PIK, and an exchange of data and ideas with respect to water use and quality, with Hydroisotop. One of the outcomes of the cooperation with PIK is the publication

Bronstert, A., Krol, M., Jaeger, A., Güntner, A., Hauschild, M., Döll, P. (2000): Integrated modelling of water availability and management in the semi-arid Northeast of Brazil. Physics and Chemistry of the Earth 25(3), 227-232.

Very intensive cooperation took place within the interdisciplinary WAVES scenario group who worked out the storylines and quantitative assumptions on the driving forces of the two reference scenarios and designed the interventions to be analyzed. Besides, it was the WAVES scenario group who organized the three policy workshops with SEMAR in Fortaleza (November 2000, March and June 2001). An outcome of the work of the scenario group is the publication:

Döll, P., Krol, M., Fuhr, D., Gaiser, T., Herfort, J., Höynck, S., Jaeger, A., Külls, Ch., Mendiondo, E.M., Printz, A., Voerkelius, S. (2001): Integrated scenarios of regional development in Ceará and Piauí. In Araújo, A., Frischkorn, H., Gaiser, T., Krol, M. (eds.): Global Change and Regional Impacts: Water Availability and Vulnerability of Ecosystems and Society in Semi-Arid Northeast Brazil. Margraf-Verlag Weikersheim (accepted).

6 RESULTS AND PUBLICATIONS

6.1 Overview

The main results of our project can be listed as follows:

1. Development of the regional water use model NoWUM (Nordeste Water Use Model)
2. Computation of sectoral water use in each municipality of Piauí and Ceará for present-day conditions (1996/98) and in 2025 (scenarios)
3. Computation of the cost of water supply to fulfil future water demands (only for Ceará)
4. Development of integrated regional scenarios for the year 2025 (as member and lead author of the WAVES scenario group)
5. Co-organization of three policy workshops with Brazilian planning agencies

The results concerning topics 1, 2 and 4 are documented in various publications which are included in Appendix 4. Here, only a concise overview over the respective results is given. Topics 3 and 5 as well as the effect of different climate data sets and climate change on modeled irrigation water use are described in the next sections of this chapter.

6.1.1 Development of the regional water use model NoWUM (Nordeste Water Use Model)

NoWUM computes withdrawal and consumptive water use in each of 332 municipalities in Piauí and Ceará, distinguishing the water use sectors irrigation, livestock, households, industry and tourism (Fig. 2). Model design is geared at scenario development. Each sectoral water use is computed as a function of a water use intensity (e.g. per-capita domestic water use of the self-supplied population) and a driving force of water use (e.g. self-supplied population). The model is strongly data-driven. It has become a module of the integrated model SIM (PIK). NoWUM is a unique model in that it computes regional-scale water use by all relevant sectors with a reasonably high spatial resolution; it takes into account the climate-dependence of irrigation water use. With some modifications, NoWUM has the potential to be applied in other data-poor regions of the globe.

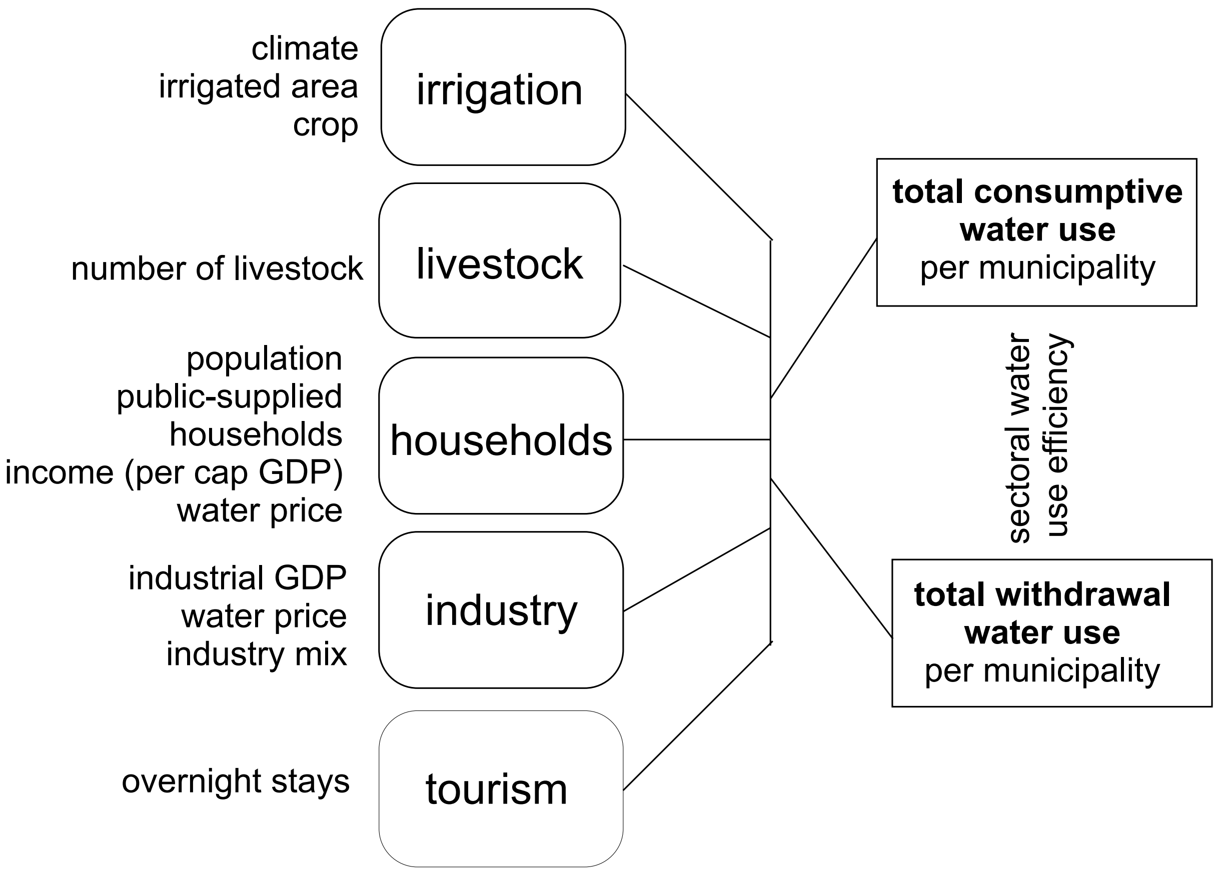

Fig. 2. Schematic overview of the regional water use model NoWUM.

Publications: Döll and Hauschild (2001a, b), Hauschild and Döll (2001, 2000), Döll et al. (2001a)

6.1.2 Computation of sectoral water use in each municipality for present-day conditions (1996/98) and in 2025 (scenarios)

Using NoWUM, the first estimate of sectoral water uses in the municipalities of Piauí and Ceará was achieved. In particular, the municipality-specific irrigation requirements for nine different crop types were determined (which allows a more efficient water use in irrigation). Scenarios of water use in the year 2025 were derived in order to support strategic water management. Two reference scenarios and the impact of interventions (policy measures) with respect to water pricing and the extension of public water supply were evaluated. The impact of climate change on irrigation water use was considered. Table 1 lists the computed water withdrawals for present-day conditions (1996/98) and for the two reference scenarios (2025), while Fig. 3 shows the spatial distribution of water withdrawal. The total water withdrawals as well as the withdrawals in the most important water use sector, irrigation, are show for 1996/98.

Table 1. Sectoral water withdrawals in Piauí and Ceará in 2025 for both reference scenarios as compared to withdrawals in 96/98 (climate change is neglected).

Scenario region (Population 1996, in million)		Water withdrawals, in 10^6 m^3/yr					
		Irrigation (irrig. area, in 1000 ha)	Livestock	Domestic	Industry	Tourism	Total
Piauí	1996/98	127.4 (13)	65.1	123.6	4.1	2.1	322.4
(2.7)	2025 RS A	279.5 (45)	64.3	130.3	4.0	8.3	486.5
	2025 RS B	209.3 (29)	77.8	125,6	3.7	6.2	422.6
Ceará	1996/98	323.9((43)	81.3	225.6	46.3	14.3	691.3
(6.7)	2025 RS A	745.0 (116)	81.7	296.9	55.2	64.6	1243.5
	2025 RS B	547.7 (83)	93.9	260.4	42.8	43.5	986.6

All computational results were delivered to the planning agencies of both Piauí and Ceará, on CD-ROM (compare Fact Sheet, in Portuguese, in Appendix 5), including Excel-files with present-day sectoral water uses in each municipality as well as water use scenarios, and crop-specific irrigation requirement specifically computed for each municipality. Information on computed water use (present-day and scenarios) is also provided at the WAVES web site (http://www.usf.uni-kassel.de/waves/szenarien/szen_uebersicht.htm).

Publications: Döll and Hauschild (2001a, b), Hauschild and Döll (2001, 2000), Döll et al. (2001a)

The specific issue of the sensitivity of computed irrigation water use on the applied climate data and on climate change is discussed in section 6.2.

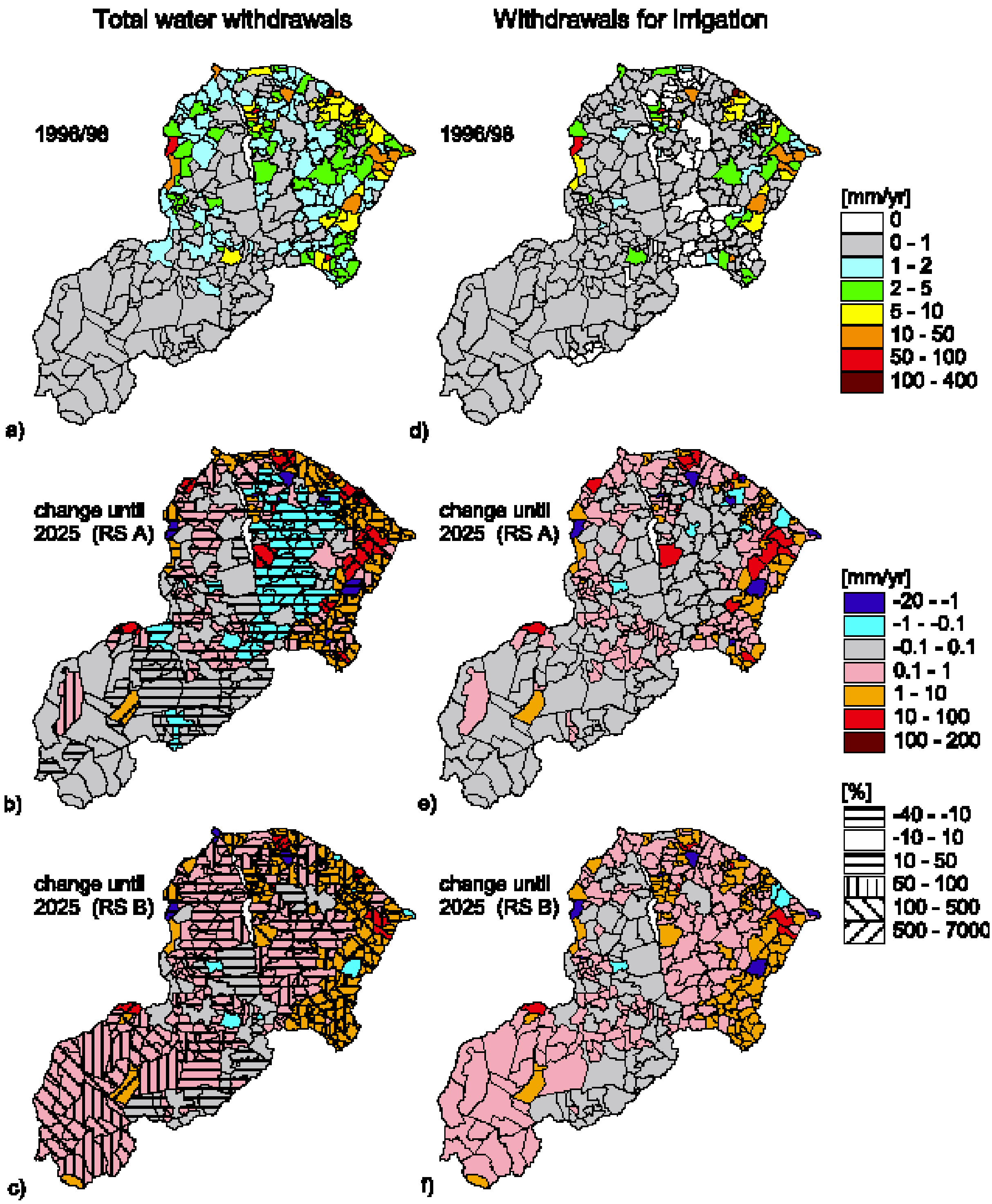

Fig. 3. Withdrawal water use in the 332 municipalities of Piauí and Ceará, in mm/yr: a) total withdrawals 1996/98 b) change of total withdrawals until 2025, RS A, c) change of total withdrawals until 2025, RS B, d) withdrawals for irrigation 1996/98, e) change of total irrigation withdrawals until 2025, RS A, f) change of total irrigation withdrawals until 2025,

RS B. The change of total withdrawals is also expressed in percent of the 1996/98 values (Figs. 4 b and c).

6.1.3 Computation of the cost of water supply to fulfil future water demands (only for Ceará)

By coupling the water use estimates of NoWUM with estimates of the per unit cost of bulk water in Ceará (data base VALOR, Araújo et al., 2001), the total costs of water supply in Ceará were determined. In particular, it was shown what the costs of fulfilling the water demands in 2025 would be, under the two reference scenarios.

The results of this work are presented in section 6.3.

6.1.4 Development of integrated regional scenarios for the year 2025 (as member and lead author of the WAVES scenario group)

In November 1998, our group organized a WAVES-Workshop on scenario development. There, the first qualitative reference scenarios were developed, and a WAVES-wide Scenario Group was formed (consisting of about 7 German members). The Scenario Group subdivided the study area Piauí and Ceará into eight scenario regions and refined the storylines of the two reference scenarios RS A ("Coastal Boom and Cash Crops") and RS B ("Decentralization — Integrated Rural Development"). The detailed storylines for each of the scenario regions can be found at http://www.usf.uni-kassel.de/waves/szenarien/reference_scenarios.html. Then, the Scenario Group quantified those driving forces which were of overall importance (the main driving forces population, gross domestic product GDP, irrigated area, potential agricultural area, urbanization etc.). For the latest documentation of the quantified main driving forces, see http://www.usf.uni-kassel.de/waves/szenarien/tabelas_cenario.pdf, in Portuguese, while the scenario assumptions are discussed in more detail in Döll et al. (2000).

Publications: Döll et al. (2001b, c), Döll et al. (2000), Bronstert et al. (2000)

6.1.5 Policy workshops with Brazilian planning agencies

Between November 2000 and June 2001, three policy workshops took place where WAVES researchers interacted with members of planning agencies of Ceará. The goal of these workshops was to make the scenarios developed by the WAVES program more relevant for water resources and agricultural planning in Ceará. In the course of the workshop, the reference scenarios were refined, and interventions (policy measures) of interest to the planning agencies were defined that were then evaluated by the WAVES models. A description of the three workshops is given in section 6.4.

Publication: Mendiondo and Döll (2001).

6.1.6 Project publications included in appendix

Döll, P., Hauschild, M. (2001a): Model-based regional assessment of water use: an example for semi-arid Northeastern Brazil. (submitted to Water International)

Döll, P., Hauschild, M. (2001b): Model-based scenarios of water use in two semi-arid Brazilian states. (submitted to Regional Environmental Change)

Döll, P., Hauschild, M., Mendiondo, E.M., de Araújo, J.C. (2001a): Modelling of present and future water use in Piauí and Ceará as a basis for water resources planning. In Gaiser, T., Krol, M., Frischkorn, H., de Araújo, J.C. (eds.): Global Change and Regional Impacts: Water Availability and Vulnerability of Ecosystems and Society in Semi-Arid Northeast Brazil. Margraf Verlag, Weikersheim. (accepted).

Döll, P., Hauschild, M., Fuhr, D. (2001b): Scenario development as a tool for integrated analysis and regional planning. Proceedings of the German-Brazilian Workshop on Neotropical Ecosystems (CD-ROM). GKSS, Hamburg (accepted).

Döll, P., Krol, M., Fuhr, D., Gaiser, T., Herfort, J., Höynck, S., Jaeger, A., Külls, Ch., Mendiondo, E.M., Printz, A., Voerkelius, S. (2001c): Integrated scenarios of regional development in Ceará and Piauí. In Gaiser, T., Krol, M., Frischkorn, H., de Araújo, J.C. (eds.): Global Change and Regional Impacts: Water Availability and Vulnerability of Ecosystems and Society in Semi-Arid Northeast Brazil. Margraf Verlag, Weikersheim. (accepted).

Mendiondo, E. M., Döll, P. (2001): Integrated dialogue under long-term perspectives as the basis for adaptive water management: a protocol of extended sustainability. Proceedings IV Interamerican Dialogue on Water Management, Foz do Iguaçu, Brazil, (http://www.iwrn.net).

6.1.7 Project publications not in appendix

Hauschild, M., Döll, P. (2000): Water use in semi-arid Northeastern Brazil. Kassel World Water Series 3, Center for Environmental Systems Research, University of Kassel, 30 pp. + Appendix (can be downloaded from http://www.usf.uni-kassel.de/usf/archiv/dokumente.de.htm).

Döll, P., Fuhr, D., Herfort, J., Jaeger, A., Printz, A., Voerkelius, S., 2000. Szenarien der zukünftigen Entwicklung in Piauí und Ceará. WAVES Report, Working Group Scenarios, Center for Environmental Systems Research, University of Kassel (can be downloaded from http://www.usf.uni-kassel.de/waves/vorl_endbericht/3_szenarien.pdf).

Hauschild, M.; Döll, P. (2001):Water management modeling in Ceará and Piauí (Northeast of Brazil). Proceedings of the German-Brazilian Workshop on Neotropical Ecosystems (CD-ROM). GKSS, Hamburg.

Bronstert, A., Krol, M., Jaeger, A., Güntner, A., Hauschild, M., Döll, P. (2000): Integrated modelling of water availability and management in the semi-arid Northeast of Brazil. Physics and Chemistry of the Earth 25(3), 227-232.

6.2 Impact of climate data and climate change on computed irrigation water requirements

In our computations of water use, five sectors are distinguished: irrigation, livestock, households, industry and tourism. Water use in the latter four sectors are expected to vary only slightly with climatic conditions, while water use for irrigation depends very strongly on climate. Thus, in the regional water use model NoWUM, the crop-specific.irrigation requirement in each municipality is computed as a function of climate, i.e. precipitation and potential (reference crop) evapotranspiration. For each of nine crops, the net irrigation requirement per unit irrigated area is computed following the FAO's CROPWAT approach (FAO, 1992) as

$$I_c = \sum_{i=1}^{n} K_{c,i} E_{p,i} - P_{eff,i} \qquad (1)$$

i: 10-day-period
n: number of 10-day-periods within the growing period (crop-specific and assumed to be the same in each municipality)
K_c: crop coefficient (crop-specific) (-)
E_p: potential (reference crop) evapotranspiration (mm/d)
P_{eff}: effective precipitation (mm/d)

Usage of effective precipitation P_{eff} instead of total precipitation P takes into account that part of the rain runs off and is therefore not available for the crops. According to the USDA Soil Conservation Service Method (as given in FAO, 1992)

$$P_{eff} = P(4.17 - 0.2\,P) / 4.17 \qquad \text{for } P < 8.3 \text{ mm/d}$$
$$P_{eff} = 4.17 + 0.1\,P \qquad \text{for } P \geq 8.3 \text{ mm/d} \qquad (2)$$

Gross irrigation requirement (or water withdrawals) are computed by dividing net irrigation requirement by the irrigation water use efficiency (0.6 for present-day conditions, 0.7 in 2025).

In order to compute the representative irrigation requirement for, let's say, present-day conditions or in 2025, it is necessary to determine the irrigation requirement not with the climate of a specific year, but with a longer time series, e.g. 30 years. This is due to the stochastic nature of climatic variables. In NoWUM, net irrigation requirements for present-day conditions are computed by first simulating 30 years of irrigation with the climate of 1951-1980 (or 1969-1998, depending on data availability) and the irrigated areas of 1996/98, and then averaging the resulting annual requirements. This procedure is more appropriate for the computation than to use long-term average climatic data as input, which, due to the nonlinearity of Eq. 1, would lead to an underestimation of the of long-term average irrigation water requirement. For the municipality of Abaiara, Ceará, Fig. 4 shows the strong climate-dependent interannual variability of irrigation requirements (assuming irrigated areas of 1996/98). The mean value of 2.8 million m^3/yr is adopted as the representative value for present-day conditions (1996/98).

6.2.1 Sensitivity of irrigation requirement to climate data sets

Daily values of precipitation and potential evapotranspiration (Penman-Monteith reference crop) in each municipality of Piauí and Ceará were provided by the Potsdam Institute for Climate Impact Research (Gerstengarbe and Güntner). Before May 2001, only a data set from 1921 to 1980 was available. Then, a modified data set which included the period 1921-98 was made available ("standard data set"), as well as an additional data set with precipitation values that were based on a higher number of measurement stations. This latter data precipitation data set is only for Ceará and the period 1961-98. The latter precipitation data set is based on approximately 200 precipitation gauging stations in Ceará, while the standard data set is based on only 30 stations (in Ceará) (Andreas Güntner, 2001, pers. comm.).

Table 2 and Fig. 5 show how the climate data sets and the selection of a representation climate period influences the irrigation water withdrawals as computed by NoWUM for the 184 municipalities of Ceará. The computation of the "best estimate" was done by using the potential evapotranspiration values of the standard climate data set and the improved precipitation estimates based on the higher number of gauging stations. The comparison between the results for the two 1951-80 time series shows that there is no significant difference between using the old climate data set (available before 2001) and the standard one. (The abscissa of Fig. 5 shows irrigation water withdrawal as computed with the old climate data set). The climate time series 1969-98 leads to an overall somewhat smaller irrigation requirement, but the differences are again minor. The impact of the improved precipitation data set that is based on a much higher number of gauging stations leads to a significant increase of the computed irrigation requirement. For Ceará, the irrigation requirement increases by more than 50% as compared to the result with the standard climate data set. Obviously, in order to obtain a good estimate of irrigation requirements, a dense network of precipation stations is necessary.

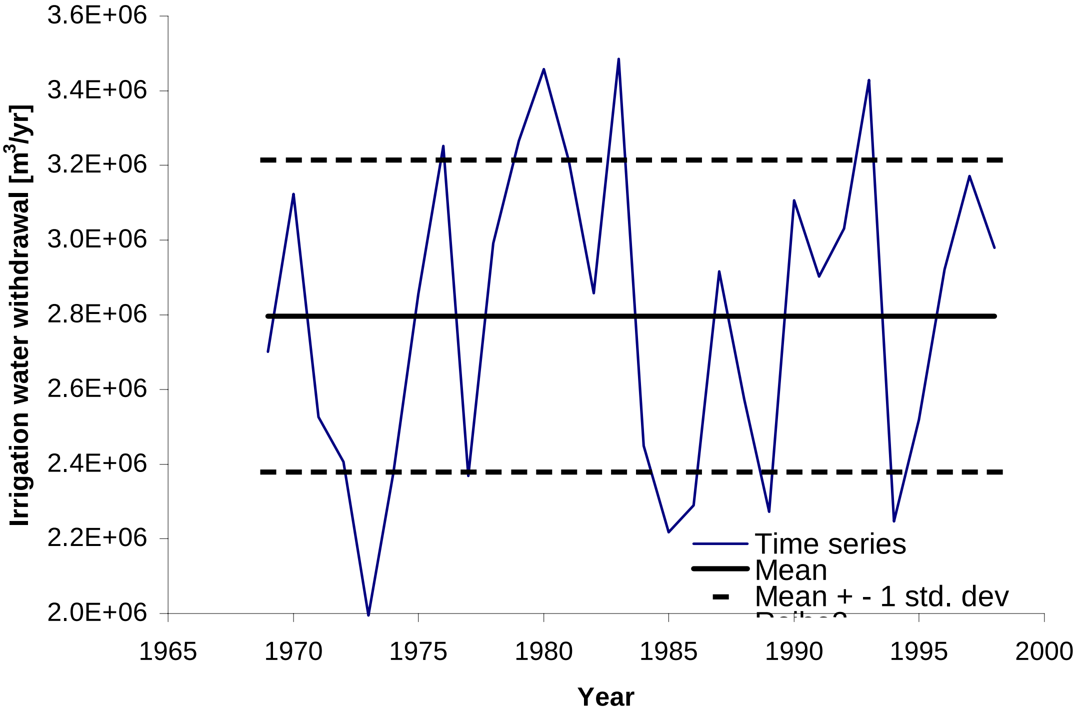

Fig. 4: Impact of interannual climate variability on irrigation requirements in the municipality of Abaiara, Ceará.

Finally, the sensitivity of the computed irrigation requirements to the choice of equation for computing potential evaporation. If the Penman-Montheith values for open water instead of the Penman-Monteith values for the reference crop is used, this would lead to an overestimation of irrigation requirments by 30%.

Table 2. Sensitivity of computed irrigation water use for Piauí and Ceará to applied climate data sets and time period.

PIK climate database	Time series	Withdrawal [10^6 m^3/yr]		
		Ceará	Piauí	Total
before May 2001	1951-1980	324	127	451
standard	1951-1980	337	121	458
standard	1969-1998	319	114	432
improved precipitation (“best estimate”)	1969-1998	486	not available	not available

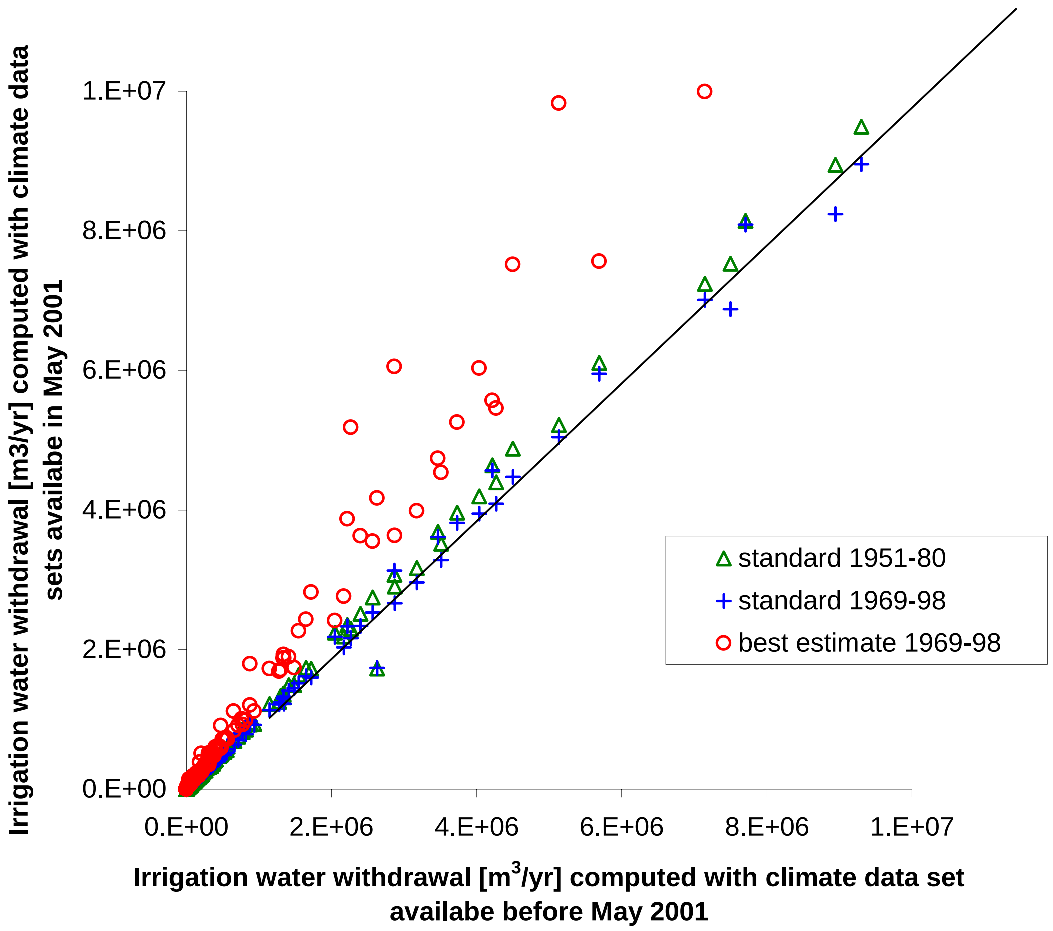

Fig. 2. Sensitivity of computed irrigation water use in the municipalities of Ceará to applied climate data sets and time period.

6.2.2 Impact of climate change on irrigation requirements

In the future, irrigation requirements will change due to a change in irrigated areas and crops but also due to climate change. The Potsdam Institute for Climate Impact Research (Gerstengarbe and Güntner) provided three climate scenarios for the years 2000 to 2050 (daily values of precipitation and potential evapotranspiration for each municipality). Two of these scenarios were derived from global climate model results by a statistical downscaling method which takes into account precipitation change in Northeastern Brazil as computed by the climate models for a 1% yearly increase of greenhouse gas concentrations, and historic station data for 1921-1980 (Werner and Gerstengarbe, 1997). In addition, a climate scenario was produced based on the assumption that long-term average precipitation is equal to the 1921-80 average. The applied climate models were the ECHAM4 climate model of the Max-Plank-Institute, Hamburg, Germany and the HadCM2 model of the Hadley Centre for Climate Prediction and Research, Bracknell, Great Britain. Of all state-of-the-art climate models, these two models show the best correspondence of modeled historic climate to observed historic climate in Northeastern Brazil. While the ECHAM4 model results in a decreasing precipitation trend, the HadCM2 model shows an increasing trend. For each climate scenario, statistical downscaling resulted in a realization of the (inherently stochastic) precipitation time series until 2025 (Fig. 6 shows the average over Ceará). The corresponding realization which assumes no climate change would lie between the two climate change scenarios.

The two climate models result in quite different precipitation developments in the study area. However, the major changes with respect to today as well a pronounced difference between the two scenarios only appear after 2025. Climate variability certainly dominates climate change. Please note that the downscaling method which is based on precipitation trends appears to result in implausible scenarios of potential evapotranspiration; the downscaled average potential evapotranspiration decreases even though according to the climate models, temperatures increase.

Irrigation requirements in the year 2025 were computed based on scenario assumption about the irrigated areas and crops in 2025 (extension of irrigation higher in RS A than in RS B, but not in each scenario region) and the climate time series 2011-40. Table 3 shows that the impact of climate change on irrigation requirements is small compared to the impact of the extension of irrigated areas. The difference between the two reference scenarios is much larger than the differences due to the three applied climate scenarios.

Table 3. Impact of climate change on net irrigation requirements in Piauí and Ceará: Increase of net irrigation requirements for irrigated areas and crops in 2025 (time series 2011-40) as compared to the present-day irrigation requirements (irrigated areas and crops 1996/98, time series 69-98).

Reference scenario	Climate scenario	Increase of net irrigation requirement by 2025 as compared to present-day values [%]
RS A	ECHAM4	125
RS A	HadCM2	111
RS A	No climate change	116
RS B	ECHAM4	66
RS B	HadCM2	56
RS B	No climate change	61

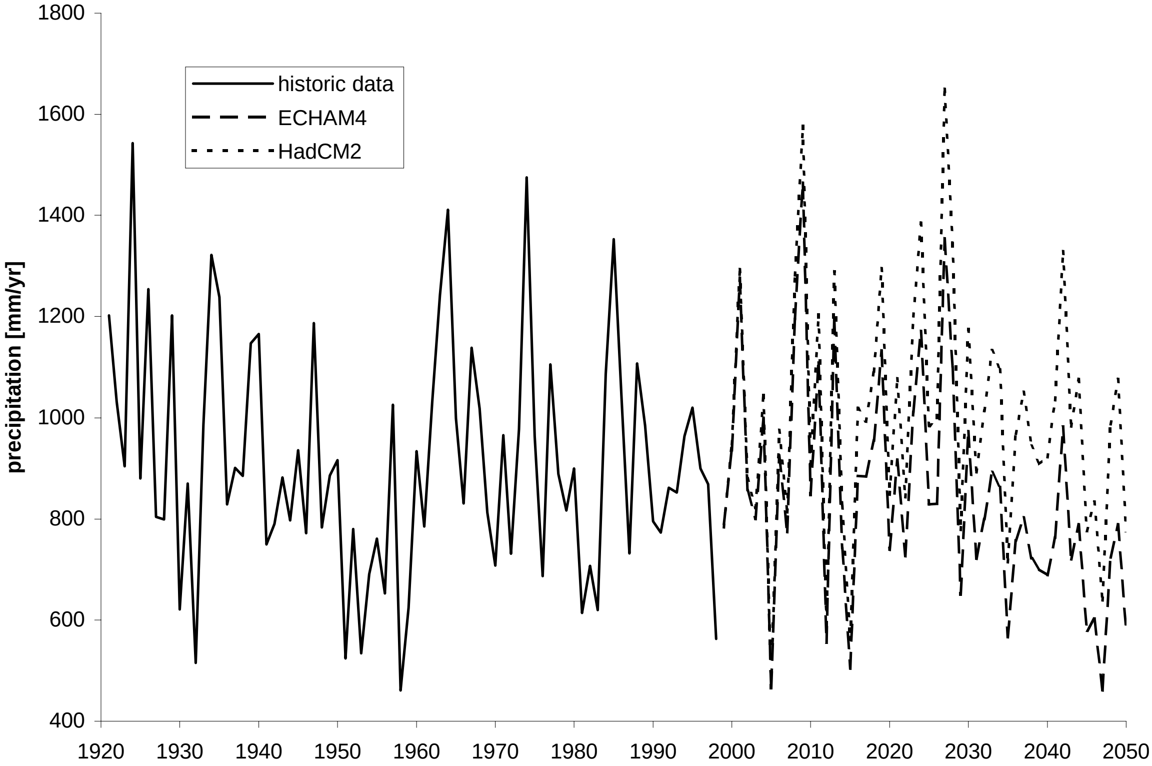

Fig. 6. Average precipitation over Ceará: historic data and downscaled climate scenarios.

6.3 Scenarios of water supply costs in Ceará

What is the cost of fulfilling the additional water demand by 2025? Increased water use will not only lead to an increase stress on water resources but also to increased costs for water supply. Water pricing is generally considered to be an important tool for water management, and in order to determine an appropriate price for water, the costs of water supply must be known (However, a price that covers only the costs of present water supply, and other types of costs like opportunity and external costs, and which is not based on marginal costs will highly underestimate the true value of water and thus prevent the efficient and sustainable use of water, Young, 1996.). Federal and state water laws in Brazil consider bulk water tariffs an important management instrument, in particular with respect to achieving a more efficient water use by the irrigation sector, which is the most important water use sector in both states.

We analyzed the cost of increased water supply that would be necessary to fulfil the water demand as computed by NoWUM for the year 2025. Only the cost of supplying bulk water (raw, untreated water) is considered here. The per unit cost of water is provided by Araújo et al. (2001) (Program VALOR). As water cost values were only derived for Ceará, the situation in Piauí could not by analyzed. Investment costs (INV) and the costs for operation, administration and maintenance (O&M) are distinguished, as well as three water sources: surface water, groundwater from sedimentary aquifers and groundwater from crystalline aquifers. In order to estimate the cost of surface water, only the construction and management of dams is taken into account, as all the rivers in Ceará would be intermittent without man-made reservoirs and could thus not provide a reliable water supply. Water pumped from shallow wells in the alluvium is also included there, as it is highly dependent on reservoir operation. For each of the eleven drainage basins of Ceará (as generally distinguished by state agencies), the average costs for the three different types of water sources were determined by de Araújo et al. (2001) (Table 4)

Table 4. Costs of bulk water supply in Ceará (Source: de Araújo et al., 2001). SW: surface water, GCA: groundwater from crystalline aquifers, GCS: groundwater from sedimentary aquifers.

Basin	O&M Cost [US$/1000m^3]			Investment Cost [US$/1000m^3]		
	SW	*GCA*	*GCS*	*SW*	*GCA*	*GCS*
Acarau	1.2	25.4	23.2	35.2	52.3	61.1
Alto Jaguaribe	2.1	27.7	28.0	80.4	67.0	30.5
Baixo Jaguaribe	2.1	27.7	28.0	40.7	54.9	54.4
Banabuiú	1.9	27.9	n/d	31.2	67.1	n/d
Coreaú	1.8	24.8	22.5	68.8	48.8	54.0
Curu	1.8	26.3	20.3	27.7	55.1	72.6
Litoral	3.1	30.1	16.3	100.3	93.7	46.9
Médio Jaguaribe	18.9	29.5	n.a.	90.1	82.5	n.a.
Metropolitana	2.9	27.2	21.5	33.2	44.4	54.2
Parnaíba	1.7	27.2	28.7	59.6	59.2	74.1
Salgado	8.3	26.1	22.9	59.2	49.2	23.5

n.a.: not applicable

In order to compute the cost of water supply in each municipality, a table was derived which defines what part of the sectoral water use (irrigation, livestock, self-supplied households, public-supplied households, industry, tourism) is taken from which of the three sources surface water, sedimentary groundwater, crystalline groundwater. This attribution table was derived with the help of our Brazilian collegue J.C. Araújo, who has many years of field experience in Ceará. As a first approximation, it is assumed that the source attribution is the same in 1996/98 and for 2025. Table 5 shows the costs for water in the four WAVES scenario regions of Ceará, for both reference scenarios RS A and RS B (assumption: no climate change).

The total (O&M+INV) current water supply cost is estimated to be 60 million 1996-US$/yr, for all of Ceará. By 2025, water supply cost is simulated to increase to 125 million 1996-U$S/yr for RS A and to 104 million U$S/yr for RS B (where water withdrawals are lower than in the case of RS B). Table 6 shows how costs might develop in each water use sector.

Table 5. Water use costs in the WAVES scenario regions of Ceará obtained by coupling water withdrawals as computed by NoWUM, a source attribution table and per unit water costs.

Scenario region	Type	Costs [in million 1996-US$]		
		1996/98	2025 A	2025 B
Metropolitan Fortaleza & Pecem	O&M	1.9	2.7	2.1
	INV	6.9	11.3	8.9
	O&M+INV	8.8	14.0	11.0
Coastal region	O&M	1.8	4.1	2.6
	INV	11.0	26.7	16.8
	O&M+INV	12.8	30.8	19.4
High potential water resources	O&M	5.7	13.4	10.0
	INV	25.5	60.9	47.3
	O&M+INV	31.2	74.3	57.3
Low potential water resources	O&M	0.8	0.8	1.1
	INV	6.2	10.4	14.3
	O&M+INV	7.0	11.2	15.4
Total	*O&M*	*10.3*	*21.0*	*15.1*
	INV	*49.7*	*109.0*	*87.3*
	O&M+INV	*60.0*	*130.0*	*103.4*

In order to understand the computed increase of costs, it is useful to compare it to the increase of water use (Fig. 7). In all of the four WAVES scenario regions but one, water costs increase approximately by the same factor as water use. In the region with low potential water resources, the O&M cost (which account for only about 10% of the total cost) increases much less which is due to a higher fraction of surface water use (which again is caused by a strong development of irrigation which, in our source attribution table is assumed to be primarily supplied by surface water).

Average per unit investment cost for Ceará is computed to be 49.3 1996-US$/1000m^3 in 1996/98 and increases by less than 5% in 2025 for both reference scenarios, while O&M cost is 10.1 1996-US$/1000m^3 in 1996/98 and decreases by less than 6%. These changes are not significant, in particular as for our calculations, the source attribution is not changed in the course of the time. The marginal cost of water, i.e. the cost of every m^3 of water that must be supplied in 2025 but not in 1996/98, is 59.6 1996-US$/1000m^3 in the case of RS A and 64.4 1996-US$/1000m^3 in the case of RS B. The higher value for RS B is mainly due to investment into reservoirs required in the region of low potential water resources.

Table 6. Sectoral costs of water supply in the scenario regions of Ceará.

Scenario regions		Irrigation	Livestock	Household	Industry	Tourism
		O&M costs [in million 1996-US$]				
Metropolitan Fortaleza & Pecem	1996	0.086	0.019	1.319	0.426	0.036
Costal Region	1996	1.267	0.098	0.290	0.102	0.049
High Potential Water Resources	1996	4.428	0.433	0.705	0.102	0.055
Low Potential Water Resources	1996	0.112	0.442	0.225	0.023	0.002
Metropolitan Fortaleza & Pecem	2025 RS A	0.241	0.030	1.712	0.540	0.184
Coastal Region	2025 RS A	3.000	0.167	0.517	0.139	0.251
High Potential Water Resources	2025 RS A	12.092	0.442	0.673	0.083	0.144
Low Potential Water Resources	2025 RS A	0.277	0.321	0.159	0.013	0.004
Metropolitan Fortaleza & Pecem	2025 RS B	0.241	0.026	1.354	0.406	0.109
Coastal Region	2025 RS B	1.842	0.128	0.358	0.092	0.146
High Potential Water Resources	2025 RS B	8.499	0.524	0.766	0.090	0.144
Low Potential Water Resources	2025 RS B	0.370	0.459	0.219	0.017	0.004
		Investment costs [in million 1996-US$]				
Metropolitan Fortaleza & Pecem	1996	0.463	0.094	4.785	1.381	0.230
Coastal Region	1996	8.176	0.572	1.695	0.358	0.220
High Potential Water Resources	1996	20.103	2.003	3.056	0.253	0.099
Low Potential Water Resources	1996	2.067	2.394	1.674	0.099	0.018
Metropolitan Fortaleza & Pecem	2025 RS A	1.331	0.149	6.838	1.751	1.199
Coastal Region	2025 RS A	20.574	0.975	3.576	0.487	1.109
High Potential Water Resources	2025 RS A	55.189	2.047	3.168	0.207	0.278
Low Potential Water Resources	2025 RS A	7.292	1.743	1.277	0.054	0.042
Metropolitan Fortaleza & Pecem	2025 RS B	1.306	0.135	5.430	1.320	0.719
Coastal Region	2025 RS B	12.828	0.746	2.285	0.323	0.660
High Potential Water Resources	2025 RS B	40.754	2.428	3.605	0.225	0.275
Low Potential Water Resources	2025 RS B	9.923	2.489	1.766	0.071	0.045

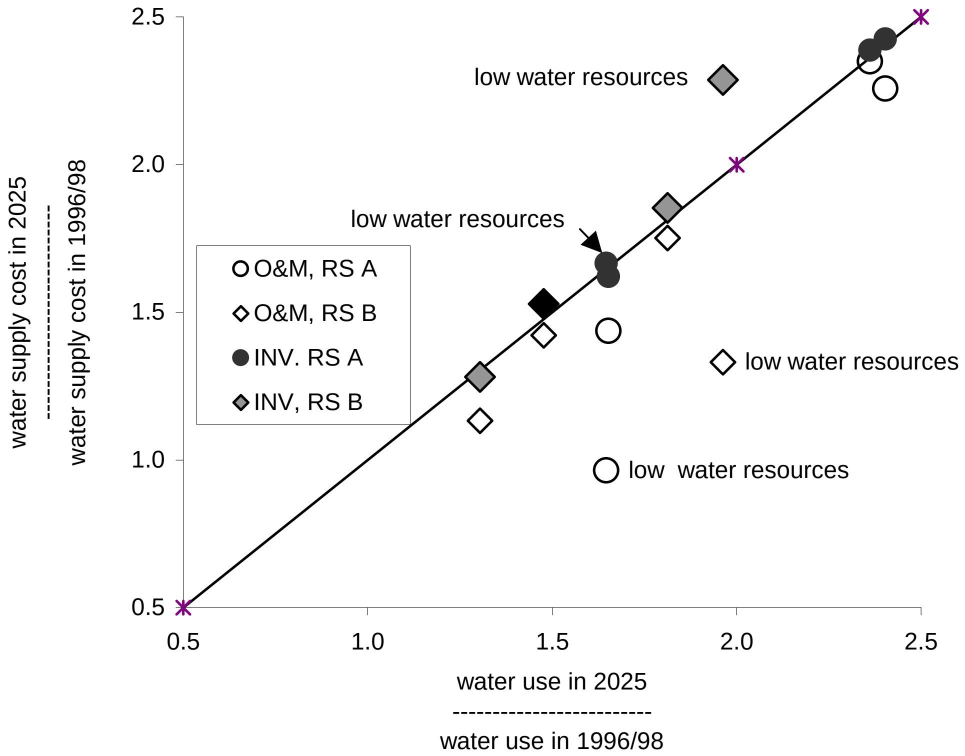

Fig. 7: Changes of water supply costs as compared to changes in water use between today and 2025, in the four WAVES scenario regions in Ceará.

6.4 Policy Workshops

Together with members of the WAVES Scenario Group, we co-organized three policy workshops of the WAVES Program between November 2000 and June 2001. Workshop participants were, in addition to German and Brazilian WAVES researchers, members of the planning ministry of Ceará, SEPLAN, the host of the workshops as well as various other institutions of the State of Ceará which are concerned with water and land resources. During the workshops, the problems of interest for water and land resources planning in Ceará were identified, the WAVES reference scenarios were refined, interventions (policy measures) that were to be evaluated by the WAVES program were discussed, and modeling results were jointly analyzed. The focus was on the sustainable use of natural resources in the context of global change.

6.4.1 First workshop: 28/29 November 2000

Goals: The workshop was held at the Secretaria de Planejamento do Ceará (SEPLAN), Fortaleza, on the rational use of natural resources, especially water and land, in the semi-arid region, with participation of SEPLAN, SRH, affiliated institutions and WAVES task groups (see the list of participants). The goals of the workshop were to exchange , between stakeholders and WAVES researchers, information on

- ongoing and planned policies to the vulnerability of the region
- scientific methods, instruments and findings,

aiming at an intensified co-operation between regional agencies, i.e. SEPLAN and SRH, and the WAVES Program.

In parallel working groups (two sessions) the focus was on identifying the most relevant policy options for reducing vulnerability to drought, both long-term oriented policies and specific drought measures. A prioritization of policy-options was made. Further, the scenarios of regional development that had been prepared by the WAVES Program were evaluated with respect to their plausibility. Their contents were refined concerning policies that should be represented in reference scenarios and in intervention variants.

Participating stakeholders: SEPLAN, SRH, COGERH

Presentation: E. M. Mendiondo presented "Desenvolvimento de Cenários como uma Ferramenta para o Planejamento Regional", authored by Döll, Mendiondo, Fuhr, Hauschild, 2000, www.usf.uni-kassel.de/waves).

Results of the first session: The discussion centered on three topics: (1) information requirements, (2) long-term policy measures, and (3) drought management. The contributions were organized according to their themes and to the possibilities of the WAVES Program to support policy makers in each issue, e.g. by offering evaluations of possible measures by simulation. Focus of the contributions was on water supply management, agro-economic policies, education and participation, and monitoring. Contributions on water demand management and agricultural technology also appeared, but somewhat less in this first workshop. For most of the (technical) issues in water supply/demand management, it was agreed that WAVES could generate useful information for evaluating the effects of such measures. Improved monitoring could strongly support the understanding of the semi-arid environment and possibly allow for effective early-warning systems for drought. Such an operational task, however, can only be fulfilled by a state agency, with only a supporting role by research programs as WAVES.

Results of the second session: One working group discussed the “Coastal Boom and Cash Crops” scenario (RS A), the other the “Decentralization — Integrated Rural Development” scenario (RS B), as developed by the WAVES program.

“Coastal Boom and Cash Crops” scenario RS A
Is the scenario plausible in its present form, including the quantification of driving forces?

RS A was generally felt to be plausible by all participants. Concerning the quantification of the driving forces, the population growth rate for Ceará was considered to be close to the most recent statistical evaluations of 1.34% per year. There were discussions on:
Gross Domestic Product (GDP): GDP growth rates were considered to be moderate and acceptable. The difference between the metropolitan region of Fortaleza and other regions in Ceará was considered to be too small.
Population with low income: It is generally estimated that when GDP increases by 10%, the proportion of the population with a low income decreases by 2.5%. This is not the case in RS A Probably, here the assumption of increasing social disparity is too rigid.
Potential agricultural area: The trend of future potential agricultural area in Ceará was considered to be inadequate. No concrete alternative assumption was proposed, however.
Irrigated area: The increase in irrigated area in the coastal region and the regions with low potential water resources was felt to be too high. Figures should be checked together with the SEAGRI. The irrigated area should be less than 5 % of the agriculture area.

What are possible policy measures that could be evaluated in intervention alternatives of the reference scenario ?

- Improved agricultural technology adapted to the semi-arid environment
- Concentration of the rural population in regions with high potential resources
- Policies to increase water supply (additional dams, connections of catchments)
- Governmental programs for reduction of the water demand
- Education policy

Of the above policies, increasing water supply and education were especially interested by participants. *Policies to increase water supply:* Participants pointed out a "Plano diretório" (Master Plan) for the development of water infrastructure elaborated by SRH/COGERH. There was a general agreement that medium-term policies will concentrate on dam construction and on connecting dams and watersheds within the state. A general opinion among participants is that water transposition of Sao Francisco river is not likely to be realized within this decade. *Education policy* : In all discussions, the issue of education (e.g. when new technologies are introduced in irrigation) was stressed again and over, and it could be worthwhile to elaborate scenario assumptions for this "driving force" of development. However, education is not considered – in a quantitative manner – in the WAVES program.

"Decentralization — Integrated Rural Development"scenario RS B
Is the scenario plausible in its present form, including the quantification of driving forces?

RS B was generally felt to be plausible, and in many respects it was considered to be even along the lines of present planning of the state authorities (in first discussions with Brazilian researchers and authorities on the storylines of both reference scenarios, RS B was still considered to be rather unrealistic). The quantification of driving forces was generally accepted. Some doubts appeared, especially because in many of the tables in the distributed documents, changes were given predominantly in relative terms, making a sub-region to sub-region comparison in absolute terms difficult. Doubts included:

- The assumed downward trend in future potential agricultural area was questioned. Even though historically, the total agricultural area shows a downward trend that is mainly due to the recession of cotton production in the 1980s and 90s.
- Developments in GDP were felt to be high for the region with low potential water resources and low for the coastal region, and should be checked.
- Urbanisation rates in the interior for RS B are even higher than for the RS A, and appear to be somewhat high. Absolute rural population numbers should be checked for consistency.

What are regional policy measures that should be assumed to be implemented in the reference version of the scenario?

Construction of new dams should be part of RS B. The 41 prioritized sites (from COGERH), with a hierarchy for 15 years, should be considered to define the RS B's assumptions. Additional dams could appear in intervention variants. The finalization of Castanhão Dam should be assumed in the reference version. *Transposition of water from the São Francisco* should not be assumed in the reference scenario. At present, both Rio Grande do Norte and Pernambuco already decided against participation in the project, and Paraíba is still considering it critically, whereas Ceará is in favour, but unable to cover the non-federal costs alone. Transposition would be an interesting intervention variant. It should be assumed in RS B that *small dams* do not increase in numbers. That reflects policies reducing the negative impact of small dams on large reservoir functionality. *Connections between catchments in Ceará* should be included in the reference scenario. A network of these connections is meant to reduce impacts in situations where a drought occurs in some specific catchments but not in others, due to heterogeneity in precipitation. The network allows geographic redistribution of water, and is in planning. *Technological improvements in irrigation systems* could reduce gross water requirements (withdrawals) by up to 40%. If the costs of these improvements are translated into costs per m^3 of water demand reduction, they are even somewhat below the usual costs per m^3 of water supply increase by dam construction. A gradual improvement of water use efficiency should be assumed in the reference scenario. *Waste water treatment, in combination with reuse, has positive effects on water quality and water supply.* The opportunities to supply Pecém industry with reuse water from Fortaleza is under study and could be part of the reference scenario. Emerging industry in the interior (primarily textile and alimentation industries) could also partly be supplied with reuse water.

What are possible additional policy measures that could be evaluated in intervention alternatives of the reference scenario ?

Treatment of irrigation drainage water and eventual reuse. This could be an important policy in preventing reservoir eutrofication, but this cannot be described by WAVES at the moment. Water pricing for the irrigation sector (not assumed in reference scenarios, cannot be simulated by WAVES models) was felt to be plausible only after 2010 to 2015. Presently, the industrial and domestic sector do pay (partly) for their water consumption, and price developments in the scenario will influence future usage; no concrete expectations on price tendencies were formulated.

6.4.2 Second workshop: 13/14 March 2001

Goals: The goals of the workshop were

- refinement of reference scenarios and interventions discussed at the first workshop in November 2000
- preparation of information transfer at the third workshop in June 2001.

In addition to plenary sessions there were two parallel working groups, one on water resources, and the other on agriculture (not described here).

Participating stakeholders: Representatives of the ministries of planning (SEPLAN), water resources (SRH), regional development (SDR), irrigated agriculture (SEAGRI) and of the hydro-meteorological service of Ceará (FUNCEME), Institute for agric. Development (IDACE), agricultural extension service (EMATERCE) and Institute for planning (IPLANCE) participated in the meeting, in addition to representatives from the German and Brazilian funding agencies (DLR, MCT and CNPq).

Presentation: E. M. Mendiondo presented “Examples of intervention scenarios of water use” computed with the water use model NoWUM. The following impacts were analyzed:

- Impact of the fraction of households connected to public water supply (Table 7)on total domestic water use (public-supplied and self-supplied) (Table 8). The increase of water use due to the extension of public water supply in the intervention scenarios is relatively small.

- Impact of water price on total domestic water use (Table 9)
- Impact of water price on industrial water use (Table 10). Assuming price increases of 11 %/yr, 6%/yr (reference scenario) and 2.5%/yr, water use intensity (withdrawal per industrial GDP) will decrease 16%, 37 % and 66 % of present water use intensity. However, in Piauí and Ceará, many companies presently do not pay at all for the water they use, and the applied concept of price elasticity (performed in NoWUM) cannot describe how water use changes when companies start to be charged.

Table 7. Fraction of population connected to public water suppply in reference and intervention scenarios. Intervention: extension of public water supply beyond the one already assumed in the reference scenarios.

	Fraction of population connected to public water supply [%]				
Scenario region	1996/98	2025 RS A	2025 RS B	2025 IS A	2025 IS B
Teresina	93.6	95	95	97	97
Metropolitan area of Fortaleza and Pecem	68.3	80	80	98	98
Coastal region	30.5	60	45	79	75
South of Piauí	41.6	50	50	58	66
Regions with high potential water resources (PI)	41.5	55	55	66	75
Regions with high potential water resources (CE)	37.1	50	50	70	79
Regions with low potential water resources (PI)	22.1	30	30	46	51
Regions with low potential water resources (CE)	33.7	40	40	62	66

Table 8. Domestic water withdrawal [10^6 m³/a] with (IS) and without (RS) extended public water supply

	1996/98	2025 RS A	2025 IS A	2025 RS B	2025 IS B
Piauí	123	130	139	126	138
Ceará	225	298	338	260	303

Table 9. Domestic water withdrawal [10^6 m³/a] as a function of water price (Fortaleza is also included in Ceará).

	1996/98	2025	2025 (RS A)	2025	2025	2025 (RS B)	2025
price increase [%/yr]		2.5	6	11	2.5	6	11
Piauí	123	187	130	63	178	126	65
Ceará	225	419	297	162	362	260	157
Fortaleza*	94	175	120	57	139	95	49

Table 10. Industrial water withdrawals [10^6 m³/yr] as a function of water price.

	1996/98	2025	2025 RS A	2025	2025	2025 RS B	2025
price increase [%/yr]		2.5	6	11	2.5	6	11
Piauí	4.1	7.3	4.0	1.7	6.6	3.7	1.6
Ceará	46.2	99.3	55.2	23.3	77.0	42.8	18.1
Fortaleza*	22.7	51.7	28.7	12.1	38.8	21.6	9.1

Results of the working group "Water resources

Method to derive a priority list for reservoir construction. An alternative prioritisation of future water supply infrastructure (cisterns, reservoirs, wells) was presented by WAVES researchers from UFC, CESR-GhK and PI, namely Araújo, Döll, Güntner, Mendiondo and Hauschild, which is based on computed scenarios of municipality-specific water stress, and aims at minimizing this stress for the period 2000-2025. This approach suggests an alternative prioritization of the construction of additional water supply infrastructure, based on the local appearance of water stress (represented by an indicator). This approach was largely supported as being complementary to the approach aiming at maximum returns in economic terms or in development potential. For example, COGERH had a former priority list dam construction in the future. The alternative approach of WAVES researchers refine this former prioritization of COGERH.

The stakeholders proposed a large variety of analyses that they considered to be useful to support water resources management in Ceará.

- Relate indicators to social data: non-economic parameters should enter; relief of water stress and development of new water-using activities require a different treatment; subsistence and market production also; per-capita indicators are most appropriate in case of stress-relief
- Elements of an intervention scenario: management of water demand and supply by wells and cisterns; water-use rights; water-quality and re-use
- Pricing in management: relevant in long-term scenario; account for capacity to pay
- Uncertainty analysis: estimate temporal development in uncertainty; analyse confidence of results
- Priority for drinking water supply: define maximum water use by irrigation per region; how are connections of catchments operated; analysis of drought in stress; stress at sectoral level
- Qualitative aspects: water-borne diseases; public health in context of water resources; water quality decrease vs. demand increase; water treatment and its costs
- Interference of small dam construction: effects on flow regulation and water quality
- Adaptation to local conditions: education; water-user associations/committees

- Interventions of environmental recovery: analyse possible recovery or damages by new infrastructure
- Integrated vision: combine demand- and supply-management; account for carrying capacity; multi-criteria analyses; support structural interventions with emergency policies.
- Comparison of studies: WAVES reference scenarios vs. long-term management plans for catchments (baixo Jaguaribe, Metropolitana)
- Inclusion of user profiles in water licence: principal use, socio-economic activity, impact on quality, social return should influence water use licences (e.g. drinking water stress next to large irrigation projects unacceptable).
- Database support for licensing: physical characteristics (soil, geomorphology, runoff, aquifers)
- Drought fund: make drought programs independent of actual political situation
- Management of prices and costs for water use: public vs. private, bonus for efficiency, price differentiation (for use, user and source)
- Re-installation of infrastructure: consider restarting use of non-active infrastructure
- Small interventions and diffuse water demand: prioritize small structural interventions (wells in crystalline, de-salinisation); define priorities in use of water-sources for diffuse demand;
- Participative action: formation of catchment committees; involve communities in operational tasks; education
- Improved efficiency in irrigation: compare irrigation centers for suited crops; identify optimal irrigation conditions; price incentives; re-use
- Transposition: study impacts on water demand
- Improved efficiency in domestic and industrial water use: what are limits to efficiency improvement; transmission losses in distribution
- Qualitative aspects: analysis (mapping) of water-born diseases

It was clarified that the WAVES program can support evaluation of some of the discussed issues, some of which were later addressed at the June workshop. For other issues, the lack of available information is hampering a quick assessment.

6.4.3 Third workshop : 27 June 2001

Goals: The goals of the workshop were:

- to present the integrated scenarios of regional development performed in the WAVES Program,
- to identify strategies of knowledge transfer/application and future cooperation

Participating stakeholders: Representatives of the ministries of planning (SEPLAN, including the minister for planning), water resources (SRH), regional development (SDR), irrigated agriculture (SEAGRI, including the minister for irrigation) and of the hydro-meteorological service of Ceará (FUNCEME), Institute for regional planning (IPLANCE).

Presentation: On behalf of the WAVES Scenario Group, E. M. Mendiondo presented “Cenários de referencia para o desenvolvimento regional” (Reference scenarios for regional development), including 1) a description of WAVES reference scenarios, 2) quantification of driving forces, 3) results of simulations, and 4) conclusions and recommendations. Among the audience, there was a lively discussion on the integrated results of WAVES and their applicability (which was regarded to be strong).

The fact-sheet “Cenários de Uso de Água en Piauí e Ceará” (Water-use scenarios in Piaui and Ceará, Brasil), with NoWUM scenarios performed at CESR-GhK along 2001 was distributed including a CD-ROM with computational results of the regional water use model NoWUM (Appendix 5)

Knowledge transfer and further application of integrated WAVES results: A strategy for knowledge transfer and application of WAVES results in the context of water and land resources planning in Ceará was developed together with the ministry of planning of Ceará, Dr. Moncia Clark. It consists of 1) a technical team in Fortaleza (at UFC), probably consisting of Ph.D. students which is capable of running and modifying the regional-scale integrated model SIM and the municipality-scale integrated model MOSDEL, and 2) a scenario group with members of the water and land resources authorities (SEPLAN, SRH, COGERH, SEAGRI, etc.). The scenario group develops scenarios, in particular intervention that are helpful for decision making. The technical team informs the scenario group about the possible questions that can be analyzed with the two integrated models and performs the model runs and presents the results to the scenario group.

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7 APPLICABILITY OF RESULTS AND EXPERIENCES

The research results are useful for state planning agencies in Piauí and Ceará. In order to enhance the applicability of the research results and their relevance for planning, three policy workshops were organized in Fortaleza. During the last workshop in June 2001, a strategy for knowledge transfer and further use of the integrated models and scenarios for planning decisions in Ceará was devised together with Dr. Monica Clark, the planning minister of Ceará (SEPLAN). In addition, research results were presented at the Environment Ministry of Piauí (SEMAR) in July 2001.

The present-day and future water use estimates as computed in our project were presented at various state institutions in Piauí and Ceará during the course of the project, in particular at those institutions which had provided data to us (e.g. AGESPISA and CAGECE, the water supply companies of Piauí and Ceará, respectively, and COGERH, the water management agency of Ceará). A CD with modeling results and pertinent publications was delivered to nine institutions (compare Appendix 1). The delivered crop- and municipality-specific values of irrigation requirement are of particular practical importance (for an efficient water use in irrigation).

The regional water use model NoWUM has the potential to be applied for water use assessments in other data-poor regions of the globe (with some modifications and collection of specific data). The methodology to derive regional scenarios could be adapted to other problem field and regions.

The interdisciplinary and international cooperation within the WAVES program has made an important contribution to the training of the involved scientist. The interdisciplinary cooperation to achieve integrated models by coupling disciplinary models has contributed to improve the systems and out-of-the-box thinking of the participants. The experiences regarding the interdisciplinary generation of qualitative-quantitative scenarios will help the members of the scenario group with any further scenario generation work.

8 PROGRESS BY OTHER RESEARCHERS

Regular literature searches during the course of the projects did not lead to the discovery of progress in research (outside the WAVES program) that was of direct interest to our research or would even have modified our research approach. However, there have been new efforts to model household water use by agent-based modeling (T. Downing, Environmental Change Institute, University of Oxford: Impact of droughts on user behaviour in Southern England; A. Ernst, Environmental Psychology, University of Freiburg: GLOWA-Danube). These approaches require significantly more data than were available in the study area of WAVES and are difficult to do at the scale of the study area.

Appendix 1

Abbreviations

AGESPISA	Águas e Esgotos do Piauí
BMBF	Bundesministerium für Bildung und Forschung, Bonn
BNB	Banco do Nordeste do Brasil
CAGECE	Companhia de Água e Esgoto do Ceará
CE	Bundesstaat Ceará
CNPq	Conselho Nacional de Desenvolvimento Científico e Tecnológico
COGERH	Companhia de Gestão dos Recursos Hídricos
DHME	Departamento de Hidrometeorologia (Teresina - PI)
DNOCS	Departamento Nacional de Obras Contra as Secas
EMATER	Empresa de Assistência Técnica e Extensão Rural
EMBRAPA / SNLCS	Empresa Brasileira de Pesquisa Agropecuária / Serviço Nacional de Levantamento e Conservação de Solos
FIEPI	Federação das Indústrias do Estado do Piauí
FNS	Fundação National de Saudé
FUNASA	Fundação National de Saudé (Piauí)
GhK	Gesamthochschule Kassel, Germany
IBAMA	Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis
IBGE	Fundação Instituto Brasileiro de Geografia e Estatistica
IPLANCE	Fundação Instituto de Planejamento do Ceará
KfW	Kreditanstalt für Wiederaufbau
NoWUM	Nordeste Water Use Model
PI	Estado Piauí (Piauí na Web)
PIB	Produto Interno Bruto
PIEMTUR	Empresa de Turismo do Piauí
PIK	Potsdam-Institut für Klimafolgenforschung, Potsdam
SEAGRI	Secretaria da Agricultura Irrigada
SEMACE	Superintendência Estadual do Meio Ambiente do Ceará
SEMAR	Secretaria de Meio Ambiente e Recursos Hídricos
SEPLAN	Secretaria do Planejamento e Coordenação do Estado do Ceará
SETUR	Secretaria do Turismo
SISAR	Sistema Integrado de Saneamento Rural
SOHIDRA	Superintendência de Obras Hidráulicas do Ceará
SRH	Secretaria dos Recursos Hídricos
UFC	Universidade Federal do Ceará
UFPI	Universidade Federal do Piauí
WAVES	Water Availability and Vulnerability of Ecosystems and Society in the Northeast of Brazil

Appendix 2

Publications related to the research project

1. Döll, P., Hauschild, M. (2001a): Model-based regional assessment of water use: an example for semi-arid Northeastern Brazil. (submitted to Water International)
2. Döll, P., Hauschild, M. (2001b): Model-based scenarios of water use in two semi-arid Brazilian states. (submitted to Regional Environmental Change)
3. Döll, P., Hauschild, M., Mendiondo, E.M., Araújo, J.C. (2001a): Modelling of present and future water use in Piauí and Ceará as a basis for water resources planning. In Gaiser, T., Krol, M., Frischkorn, H., de Araújo, J.C. (eds.): Global Change and Regional Impacts: Water Availability and Vulnerability of Ecosystems and Society in Semi-Arid Northeast Brazil. Margraf-Verlag Weikersheim (accepted).
4. Döll, P., Hauschild, M., Fuhr, D. (2001b): Scenario development as a tool for integrated analysis and regional planning. Proceedings of the German-Brazilian Workshop on Neotropical Ecosystems (CD-ROM). GKSS, Hamburg (accepted).
5. Döll, P., Krol, M., Fuhr, D., Gaiser, T., Herfort, J., Höynck, S., Jaeger, A., Külls, Ch., Mendiondo, E.M., Printz, A., Voerkelius, S. (2001c): Integrated scenarios of regional development in Ceará and Piauí. In Gaiser, T., Krol, M., Frischkorn, H., de Araújo, J.C. (eds.): Global Change and Regional Impacts: Water Availability and Vulnerability of Ecosystems and Society in Semi-Arid Northeast Brazil. Margraf-Verlag Weikersheim (accepted).
6. Mendiondo, E. M., Döll, P. (2001): Integrated dialogue under long-term perspectives as the basis for adaptive water management: a protocol of extended sustainability. Proceedings IV Interamerican Dialogue on Water Management, Foz do Iguaçu, Brazil, (http://www.iwrn.net).