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WAVES
Water Availability and Vulnerability of Ecosystems and Society in the Northeast of Brazil

Large Scale Water Use Model NoWUM

for Modeling Water Management
in Ceará and Piauí in Northeast of Brazil

Version 1.0
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1 Overview

The water use model NoWUM (**No**rdeste **W**ater **U**se **M**odel) calculates both withdrawal water use (quantity of water withdrawn from its natural location) and consumptive water use (quantity of water lost to evapotranspiration). The use quantity best suited for the assessment of water scarcity, water depletion (quantity of water used that cannot be reused), is a quantity in-between withdrawal use and consumption use, which due to the lack of information on water quality is not yet computed in the present model version 1.0. Within NoWUM, five water use sectors are distinguished: irrigation use, livestock use, domestic use, industrial use and tourism use.

The irrigation water use is calculated with the methodology of FAO (FAO, 1992). Livestock water use is computed as a function of livestock-specific water use and numbers of the different livestock types. With respect to domestic water use, the specific water use of people connected to the public water supply and those not connected are differentiated. Two methods are used to calculate the industrial water use: one based on the assessment of different water sources (public supply, self-supply, raw water supply); the second multiplies the industrial gross domestic product with a water use intensity per industrial branch. Multiplying the touristic overnight stays with a touristic water use per overnight stay gives the water use in the tourism sector.

Computations are performed on the municipal scale for all municipalities of Ceará and Piauí in the reference year 1996. Here, Ceará consists of 184 and Piauí of 148 municipalities. The municipalities in Ceará are numbered sequentially from 1 up to 184, those of Piauí from 185 to 332. The output of NoWUM are monthly sectoral withdrawal and consumptive water use values in each municipality. However, in the case of livestock water use and industrial water use, the monthly values are derived from annual averages, while in the case of irrigation they are the sum of 10-day-values.

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2 Irrigation water use

2.1 Method

The consumptive irrigation water use (net irrigation requirement) is computed following the method of CROPWAT (FAO, 1992). The crop-specific net irrigation requirement within one growing period I_c is calculated as

$$I_c = \sum_{i=1}^{n} K_{c,i} E_{p,i} - P_{eff,i} \qquad \text{(F 2.1)}$$

i: *10-day-period*
n: *number of 10-day-periods within the growing period (crop-specific)*
K_c: *crop coefficient (crop-specific) [-]*
E_p: *potential evapotranspiration [mm/d]*
P_{eff}: *effective precipitation [mm/d]*

Using effective precipitation instead of total precipitation P takes into account that not all the rain is available to the crops. According to the USDA Soil Conservation Service Method (as given in FAO, 1992),

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

2.2 Climate data input

NoWUM requires daily values of precipitation and potential evapotranspiration, which are provided by the WAVES-subproject *Large-scale Water Budget Model*.
As the FAO-approach uses 10-day time steps, NoWUM aggregates daily values of precipitation and evapotranspiration into 36 time steps per year. The *Integrated Model SIM* of WAVES handles with 365 or 366 days per year, respectively. Hence, NoWUM sums up three times 10 days (April, June, September, November); 10, 10 and 11 days (January, March, May, July, August, October, December); in February 10, 10 and 8 or 9 days to get three time steps per month.

2.3 Input of crop data

The crop data required are:
1. irrigated areas per crop in each municipality
2. crop-specific data like planting date, growing periods and crop coefficients per growing period.

First, we determined nine main irrigated crops classes (Table 1). The crop-specific planting date was derived from annual schedules of DNOCS irrigation perimeters in Ceará and Piauí (DNOCS 1994a, 1995a, 1996a) and the recent Agricultural Census (IBGE 1998a, 1998b),

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while data on crops coefficients and length of growing period are taken from CROPWAT (FAO, 1992).

Table 1: NoWUM crop classes of irrigated crops: relation of single crops to crop classes, growing period of crop classes and used crop data set (crop coefficients K_c and growing periods) per crop class from FAO (1992).

class no	crop class	included crops	growing period [days]	crop type in FAO (1992), for which crop-specific data are used
1	banana	banana	360	banana
2	beans	beans	90	beans
3	cotton	cotton	140	cotton
4	fruit trees	acerola, cajá, coconut, guava, graviola, jaca, orange, lemon, mango, papaw, passion fruit, urucum, uva	360	citrus
5	grass	grass	360	grass
6	maize	maize	130	maize
7	rice	rice	120	rice
8	sugar cane	sugar cane	360	sugar cane
9	vegetables	melon, onion, pumpkin, tomato, water melon	120	tomato

2.3.1 Irrigated areas in 1996/98

The different informations about the size of irrigated areas at state level in Ceará and Piauí diverge widely. The Agricultural Census of Ceará and Piauí (IBGE 1998a, 1998b) provides uniform informations for both states, but Brazilian experts say that the total irrigated areas published by IBGE are overestimated.

For Ceará, we used the most reliable information from COGERH (1995, 1998a) and SRH (1998), instead of data of the Agricultural Census. COGERH keeps a register of total irrigated farm land in some municipalities of the Curu and the Jaguaribe valley. SRH registers all irrigation licenses given to farmers in Ceará. These licenses include also the irrigated area per crop. The total irrigated area per municipality is taken from the COGERH and the SRH-register. The lacking data in 23 municipalities are filled with downscaled IBGE data considering expert knowledge. Because in the municipalities Ico and Morada Nova the registered data seem to be much to high, they are replaced with data from the Agricultural census. Here licenses are already given for public irrigation projects which will be implemented in the future.

In Piauí, data of irrigated areas are taken from the Agricultural Census, because more reliable data are lacking. There is no reasonable correlation between the total irrigated area per mu-

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nicipality and the sum of the harvested areas of significant irrigated temporary crops per municipality, both given in the Agricultural Census of Ceará and Piauí (IBGE 1998a, 1998b). In many municipalities the total irrigated area is considerably less than the sum of the areas of the temporary crops. Additionally the permanent crops should be integrated. That calls the given total irrigated area in question. Hence, the harvested areas of irrigated temporary crops per municipality are considered as their irrigated areas in the year 1996. Furthermore, the harvested area of banana and all fruit trees are set as their irrigated areas assuming that these crops are always irrigated. The total irrigated area per municipality is calculated as the sum of the harvested area of the irrigated temporary crops, the harvested area of banana and the harvested area of fruit trees. The total irrigated area is scaled down on 13170 ha, because Brazilian experts don't believe in 18148 ha irrigated land in Piauí in 1996. For this purpose, the size of irrigated areas in the municipalities close to markets (Floriano, Miguel Alves, Oeiras, Parnaiba, Picos, Piripiri, São Raimundo Nonato, Teresina and União, all together 8625 ha) are retained. In all other municipalities the irrigated area is reduced by factor 3.

2.3.2 Irrigated areas in 2025

For the year 2025 is assumed that all big public irrigation projects planned in 1998 will be implemented in the specified municipalities given in Lopes Neto (1998). In addition, an increase of the private irrigated area is assumed per scenario region. The additional total private irrigated area per scenario region is equally distributed to all municipalities of the region. Table 2 summarizes the change in total irrigated area per scenario region for both reference scenarios.

Table 2: Scenario of the increase of the irrigated areas

	irrigated area in ha		change of irrigated area in %
Scenario region	1996	2025	1996-2025
Teresina	1018	4072	+ 300
Metropolitan area of Fortaleza and Pecem	695	4170	+ 500
Coastal region	10476	41904	+ 300
South of Piauí	1470	11760	+ 700
Region with high potential water resources (Piauí)	10402	62412	+ 500
Region with high potential water resources (Ceará)	28138	112552	+ 300
Region with low potential water resources (Piauí)	103	309	+ 200
Region with low potential water resources (Ceará)	3964	15856	+ 300
Total (Piauí and Ceará)	56266	252035	+ 348

Not only the total irrigated area, but also the crop mix is changed in the scenarios. 50% of the new irrigated area per municipality gets the same percentual crop quotas as in 1996/98. The other part is planted after the standard crop mix of 2025. A standard crop mix means the average state's crop mix. Therefor, Ceará and Piauí have different standard crop mixes. The expected changes to the crop mixes 1996/98 come up with the standard crop mixes of 2025.

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Brazilian experts expect that the percentage of banana, fruit trees, vegetables and cotton will rise, the percentage of beans, maize and grass will remain at the same size, and the percentage of rice and sugar cane will decrease (Table 3).

Table 3: Standard crop mixes 1996/98 and 2025 in Ceará and Piauí [in % per crop class]

crop class	CE 1996/98	CE 2025	PI 1996/98	PI 2025
banana	5,4	6	7,4	10
beans	18,0	18	6,2	9
cotton	3,9	7	0,2	5
fruit trees	21,2	25	8,8	25
grass	12,4	12	5,8	6
maize	5,2	5	6,1	7
rice	24,4	18	31,4	28
sugar cane	3,9	0	26,2	0
vegetables	5,6	9	4,3	10

2.4 Calculation of irrigation water use

In NoWUM, the net irrigation requirement *irr_req* of a planted area is calculated as

$$irr\_req[i][l][k] = petp[i][l] * K_c[l][k] - raineff[i][l] \qquad \text{(F 2.2)}$$

i: *municipality*
l: *ten-days-time-step of the year*
k: *crop class*
irr_req: *irrigation requirement [mm]*
petp: *potential evapotranspiration [mm]*
K_c: *specific crop coefficient [-]*
raineff: *effective precipitation [mm]*

The irrigation requirement is calculated for each municipality *i*, for every ten-day time step of the year *l* and for all crops *k*, which are planted in the municipality. The crop coefficient K_c varies within the growing season. It is 0 before the crop's planting and after its harvest. Altogether four development steps are distinguished with fixed crop coefficients during the first and the third step. The coefficient during the second and the fourth step augments or decreases linearly. During the second step it starts with the value of the first step and finishes with the value of the third step. During the fourth step it starts with the value of the third step and finishes with the given final value of the fourth step. Table 4 shows an example:

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Table 4: Planting date, duration and crop coefficients of growing phases of crop 1:

crop 1		phase 1	phase 2	phase 3	phase 4
planting day [day of the year]	10				
duration of growing periods [number of days]		30	40	50	30
crop coefficient K_c		0.5	$0.5+\frac{1.1-0.5}{1+40/10}*n$ n: number of time steps	1.1	$1.1+\frac{1.0-1.1}{1+30/10}*n$ n: number of time steps

In the model source code, the crop coefficient for each crop and each time step is selected before it is used for the calculation of the irrigation requirement.

If the irrigation requirement for a crop of each municipality [mm = l/m²] is multiplied with the municipal irrigated area of the respective crop, the water amount for irrigation water results.

$$wat\_irr[i][l][k] = irr\_req[i][l][k] * area[i][k] \qquad \text{(F 2.3)}$$

i: *municipality*
l: *time step*
k: *crop type*
wat_irr: water amount for irrigation [m³/time step]
irr_req: irrigation requirement [m³/m²]
area: planted area with crop k [m²]

Summing over all crops and over each month, the monthly consumptive use of irrigation within one municipality *con_irr[i][j]* is obtained. The withdrawal water use is computed as

$$wd\_irr[i][m] = \frac{con\_irr[i][m]}{eff\_irr[i]} \qquad \text{(F 2.4)}$$

i: *municipality*
m: *month*
wd_irr: total irrigation withdrawal water use [m³/month] per municipality
con_irr: total irrigation consumptive water use [m³/month] per municipality
eff_irr: irrigation water use efficiency of municipality [-]

NoWUM works with a constant water use efficiency of 0.6 for all municipalities in 1996/98 according to Brazilian expert knowledge. In the future Brazilian experts expect that the irrigation water use efficiency will increase to 0.7. The higher efficiency considers the technological change; since NoWUM does not include a price control of irrigation. Moreover, this version does not consider multiple cropping (planting crops with short growing periods two or three times a year) yet, consequently the irrigation water use is underestimated.

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3 Livestock water use

Based on the Agricultural Census (IBGE 1998a, 1998b), eleven types of livestock are distinguished. For 1996 the number of animals per species are taken from the Agricultural Census. In the scenarios of the future animal populations grow with the same annual population growth rates as used for the human population per municipality. The withdrawal water use for livestock is computed by summing up the products of the livestock-specific water use (Table **5**) and the number of that livestock in each municipality. The consumptive water use is computed by multiplying the withdrawal water use with a typical livestock water use efficiency of 1.0 (USGS, 1998). Only yearly values are computed, which are - in order to obtain monthly values - just divided by twelve.

Table 5: Mean daily water volume consumed by livestock species [l/d/cap]. Values calculated from given minimum and maximum values in EMPRAPA-CPATSA/SUDENE (1984). For donkey and mule the value of horse is assumed; for rabbit, poultry and quails the value of chicken.

species	daily consumed water volume [l/d/cap]
cow	68.0
pig	11.0
horse, donkey, mule	54.5
sheep, goat	8.5
chicken, poultry, quail, rabbit	0.3

4 Domestic water use

4.1 Method

Domestic water use is the product of population and the water use per person. People connected to the public water supply (piped water supply) are differentiated from those that are not connected. While the water use of people connected to the public water supply is determined from municipality-specific monthly data on connected households and supplied volume, the water use of people not connected to the public water supply is assumed to be a constant in the present version of NoWUM. For the scenarios of the future the water use per capita of a person connected to the public water supply is modeled as a function of the water price and the average income of the person.

4.2 Input data of population and public water supply volumes

4.2.1 Data for the present state

NoWUM requires data of the total population and the population connected to public water supply. The latest population data (total, urban and rural) are published in the Demographic Census of IBGE (1997), reference day 01-08-1996. With monthly growing rates of population per municipality, which we took from internal reports of the public water supply companies

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AGESPISA (1997) and CAGECE (1997), we computed monthly total and urban population for the year 1997. The supplied population is calculated as follows for every municipality:

$$popsupp = \begin{cases} hh_{conn} * hhsize_{urban} & \text{if } hh_{conn} * hhsize_{urban} < popurban \\ popurban & \text{if } hh_{conn} * hhsize_{urban} \geq popurban \end{cases} \qquad \text{(F 4.1)}$$

popsupp: *supplied population of municipality*
popurban: *urban population of municipality*
hh_{conn}: *amount of households connected to public supply*
$hhsize_{urban}$: *urban household size per municipality*

The data of amount of households connected to public supply were derived from internal reports of AGESPISA (1997), CAGECE (1997), FNS (1997), SISAR (1998), FUNASA (1998) and SOHIDRA (1999) as well as the data of urban household size from the Demographic Census on IBGE (1997). In the present model version, the supplied population is calculated outside of NoWUM.

For computing the specific water use of people connected to the public water supply, the produced water volume of the supply companies for each municipality are necessary. In the accessible internal reports of 1997 from AGESPISA, CAGECE and FNS, these data are only given by CAGECE for all months and by AGESPISA from January up to March 1997. Instead of this, we take the billed water volumes, provided by all companies for all months, as input data, although the billed water volume in general is smaller than the produced (and supplied) volume, in some municipalities up to factor 2. If households have no water meter, they pay for a fixed volume of 10 m³, although they probably consume more water. This could explain the large difference between the two water volumes. Finally the water use efficiencies per municipality are read from a separate input file, although we have no local data yet.

4.2.2 Data for the scenarios of the future

The WAVES working group *Scenarios* designed two reference and one intervention scenario up to the year 2025 for the eight scenario regions. The two reference scenarios are (A) the *"Coastal Boom and Cash Crops"-Scenario* (globalization) and (B) the *"Integrated Rural Development"-Scenario* (decentralization). The report of working group *Scenarios* presents the story lines of the scenarios and detailed information on how the working group came up with the quantification of the driving forces in detail. The growth of the total population is the same in both scenarios (

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Table 6) but it is different in the scenario regions in scenario A and B (Table 7). In the field of water management scenarios, assumptions of the percentage of persons connected to public water supply were made for the reference and intervention scenarios (Table 8). The intervention scenario assumes still a larger expansion of the public water supply as already done in the reference scenarios. The explicit increase of the connections to public water supply expresses the structural change in the future.

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Table 6: Population growth in Ceará and Piauí from 1996 to 2025 for the reference scenarios

year	total population (million)	year	total population (million)
1996	9.46	2011	10.91
1997	9.57	2012	10.99
1998	9.68	2013	11.07
1999	9.79	2014	11.14
2000	9.90	2015	11.22
2001	10.00	2016	11.29
2002	10.10	2017	11.37
2003	10.20	2018	11.44
2004	10.29	2019	11.51
2005	10.39	2020	11.58
2006	10.48	2021	11.65
2007	10.57	2022	11.72
2008	10.66	2023	11.79
2009	10.75	2024	11.86
2010	10.83	2025	11.93

Table 7: Quota of population per scenario region on total population in Ceará and Piauí

Scenario region	1991	1996	RSA 2025*	RSB 2025*
Teresina	6.7	6.9	8.1	7.3
Metropolitan area of Fortaleza and Pecem	26.1	27.6	35.4	30.6
Coastal region	12.7	12.8	17.4	13.3
South of Piauí	3.1	2.9	2.4	2.9
Regions with high potential water resources	33.9	32.9	26.9	31.9
Regions with low potential water resources	17.6	16.9	9.8	14.0

Table 8: Population connected to public water supply

	Fraction of population connected to public water supply (in % of the urban population)				
scenario region	1997	2025 RSA*	2025 RSB*	2025 ISA*	2025 ISB*
Teresina	93.6 (100)	95 (98)	95 (98)	97	97
Metropolitan area of Fortaleza and Pecem	68.3 (70)	80 (82)	80 (82)	98	98
Coastal region	30.5 (57)	60 (80)	45 (64)	79	75
South of Piauí	41.6 (97)	50 (100)	50 (82)	58	66
Regions with high potential water resources (PI)	41.5 (87)	55 (92)	55 (79)	66	75
Regions with high potential water resources (CE)	37.1 (68)	50 (77)	50 (67)	70	79
Regions with low potential water resources (PI)	22.1 (76)	30 (81)	30 (71)	46	51
Regions with low potential water resources (CE)	33.7 (69)	40 (73)	40 (67)	62	66

* RS: reference scenario / IS: intervention scenario

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For the future NoWUM calculates the water use per capita per person connected to public water supply as a function of prices and income (see below). The scenarios include rates of change in gross domestic product per capita per scenario region (Table 9) as well as an annual rising of the water price. In order to come up with a price rate a ten year time series (1989-1998) of water tariffs from CAGECE was analyzed. In this period occurred several monetary reforms reflecting the inflation. The base tariff for the first 15 m³ increased at 11% per year from 1989 to 1998. Nowadays, CAGECE's water price covers the operation and maintenance costs (O&M costs). They expect that the O&M costs will rise in future. Because the water tariffs are still high in Ceará, for the scenarios a constant water price rate of 6% per year is assumed for all scenarios in all scenario regions.

Table 9: Scenarios of the growth rate of gross domestic product (GDP) per capita per scenario region. Constant annual rates are assumed between 1996 and 2025.

	annual growth of GDP per capita between 1996 and 2025 [%]	
Scenario region	RS A	RS B
Teresina	2.5	2.2
Metropolitan area of Fortaleza and Pecem	2.7	2.2
Coastal region	2.7	2.2
South of Piauí	2.7	2.2
Regions with high potential water resources	2.7	2.4
Regions with low potential water resources	2.5	2.2

4.3 Computation of domestic water use

In NoWUM, the specific water use of people connected to the public water supply and those not connected are differentiated. We have no information on the water use of people not connected to the public water supply. As a first estimate, we assume a value of 50 l/d/p, a value defined by Gleick (1996) as the basic human water requirement. This might underestimate water use particularly when people have their own private wells. Thus, the domestic withdrawal water use is computed as follows:

$$wd\_domestic[i][m] = popsupp[i][m] * con\_supp[i][m] + (poptotal[i][m] - popsupp[i][m]) * con\_nsupp[i][m] \qquad \text{(F 4.2)}$$

i: *municipality*
m: *month*
wd_domestic: *total withdrawal use of municipal population [m³/month]*
popsupp: *supplied population [-]*
p_supp: *withdrawal use per supplied person [m³/month/p]*
poptotal: *total population of a municipality [-]*
p_nsupp: *withdrawal use per non-supplied person [m³/month/p]*

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The consumptive water use is computed by multiplying the withdrawal water use with a typical domestic water use efficiency of 0.2, which is the average value for the USA (USGS, 1998)

Economists use the concept of elasticities to consider the responsiveness of consumers' purchases to varying price. A measure of this responsiveness, the elasticity of demand with respect to a demand-determining variable, is defined as the percentage by which the quantity taken changes in response to a one percent change in the variable. The most frequently used elasticity concept is the price elasticity, which is defined as the percentage change in quantity taken if price is changed one percent. The income elasticity of demand is a related concept: it measures the percentage change in quantity demanded associated with one percent change in consumer income. Almost all estimates of long run price elasticity of residential water demand in the U.S. seem to fall between -0.3 and -0.7, meaning that other factors held constant, a ten percent increase in price would lead to between a three and seven percent decrease in amount purchased (Young, 1998). Income elasticity is found to be small but positive; an increase in income brings about a less than proportional increase in quantity consumed.

The future water use per capita per person connected to water supply is calculated as a function of the water price and the average income (GDP per capita). It is calculated for each municipalities as follows:

$$V_{j+1} = \left[\left(\varepsilon_{p,j+1} * r_{p,j+1} + \varepsilon_{i,j+1} * r_{i,j+1}\right) + 1\right] * V_j \qquad \text{(F 4.3)}$$

j: *year*
V_{j+1}: *volume consumed per person connected to public water supply in year j+1*
ε_p: *price elasticity in year j+1*
r_p: *price rate in year j+1*
ε_i: *income elasticity in year j+1*
r_i: *change rate of gross domestic product per capita in year j+1*

NoWUM uses a linear decreasing price elasticity from 1996 to 2025; it starts with -0.55 (value for Northeast of Brazil, (BNB/PBLM, 1997)) in 1996 and ends with -0.3 (average value for Europe and U.S.). According to Gomez (1987), NoWUM uses a constant income elasticity of 0.7. The Brazilian value of 0.78 was reduced, because the scenarios consider explicitly new connections.

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5 Industrial use

5.1 Methods and calculation

Two methods were developed to calculate the range of the industrial withdrawal water use. The value of method 1 represents the minimum and is probably still too low and the value of method 2 the maximum of the range. The "real" value is somewhere in-between. The consumptive water use is calculated out of the withdrawal water use, using a industrial water use efficiency of 0.2 (USGS, 1998).

5.1.1 Method 1

$$wd\_industry\_1 = \begin{cases} IWUWW + IWUSS + IWURW & \text{if data available} \\ wd\_industry\_2 * c & \text{if no data available} \end{cases} \qquad \text{(F 5.1)}$$

i: *municipality*
m: *month*
IWUWW: *industrial water supplied by waterworks [m³/month]*
IWUSS: *self-supplied industrial water use [m³/month]*
IWURW: *industrial raw water supplied by COGERH [m³/month]*
wd_industry_1: *total industrial withdrawal water use [m³/month] per municipality calculated with method 1*
wd_industry_2: *total industrial withdrawal water use [m³/month] per municipality calculated with method 2*
c: *correction factor [-] (diminishing wd_industry_2)*

5.1.2 Method 2

$$wd\_industry\_2[i][m] = \sum_{b=1}^{19} IGDP_b[i][m] * WUI_b \qquad \text{(F 5.2)}$$

i: *municipality*
m: *month*
b: *industrial branch (19 are distinguished)*
wd_industry_2: *total industrial withdrawal water use [m³/month] per municipality calculated with method 2*
IGDP: *industrial gross domestic product per industrial branch [US$ 1995]*
WUI: *water use intensity per industrial branch [m³/1000 US$ 1995]*
(adapted from German industrial data of 1995)

In the scenarios of the future the industrial water use is also a function of prices in both options as showed in the following.

$$V_{j+1} = \left[\left(\varepsilon_{p,j+1} * r_{p,j+1}\right) + 1\right] * V_j \qquad \text{(F 5.3)}$$

j: *year*
V_{j+1}: *industrial water volume in year j+1*
ε_p: *price elasticity in year j+1*
r_p: *price rate in year j+1*

Prices stand indirectly for technological change. Due to the lacking of industrial specific data, NoWUM uses also a price rate of 6% per year for the industrial water use scenarios as derived

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from CAGECE's data for the domestic water use. The price elasticity decreases linear between 1997 and 2025 from -0.74 (value for Northeast of Brazil, BNB/PBLM (1997)) to -0.4 (average value for Europe).

5.2 Input data

5.2.1 Input of industrial water use data

Industry gets water from different sources. Mostly the small industry is supplied by the public waterworks (IWUWW). Often industry additionally supplies itself from own wells or reservoirs (IWUSS). In Ceará water-intensive industry like breweries and industrial districts buy raw water (IWURW) directly from COGERH, the state company of water management who manages the big reservoirs.

The IWUWW for municipalities of Piauí were averaged over data of AGESPISA for April 1998 and January 1999. For Ceará only data of CAGECE-supplied municipalities were available; the monthly averages of 1998 were used.
Marwell Filho (1995) published the self-supplied industrial water use for the watersheds of Piauí. The author remarked that these data are probably too low, because making this investigation, firms were interviewed by telephone and not all firms answered. To get an IWUSS per municipality, the water was equally divided to all municipalities within a basin having firms in 1991. Piauí's capital Teresina has the biggest industrial concentration of Piauí. It's special position was taken into account assigning half of the self-supplied water in the "Poti" basin to Teresina and the rest equally portioned to all other municipalities in the watershed. The IWUSS of Piauí is 1.57 times higher than the IWUWW of Piauí (state averages). This unique scale factor was used to compute the IWUSS for the municipalities of Ceará already having an IWUWW.

The IWURWs for the four concerning municipalities of Ceará were taken over from COGERH's bill 1998.

5.2.2 Input of correction factor c

In some municipalities the situation is contradictory: they don't have an industrial water use (IWU) but have an IGDP. Their IWU could be computed by method 2 described above. Therefore, the correction factor c was necessary. It reduces the IWU to a size corresponding with the measured data of IWU. The $c_{Ceará}$ is 0.554 and $c_{Piauí}$ is 0.215. The c for one state each was calculated as

$$c = \frac{\sum_{i=1}^{n} IWUWW_i + IWUSS_i + IWURW_i}{\sum_{i=1}^{n} wd\_industry\_2_i} \qquad \text{(F 5.4)}$$

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5.2.3 Input of industrial water use intensity

The application of method 2 needs an industrial water use intensity per industrial branch. Since these data are not yet available for Brazil, we used data from German industry. To link the Brazilian with German data, a common classification of industry branches was necessary. Even Ceará and Piauí have some differences in their classifications. Therefore, the German system was taken as basis and all data were transformed into this classification considering 19 industrial branches.

Table 10: Average water use intensity (WUI) per industrial branch for Germany 1995

Industrial branch	Average WUI [m³/ 1000 US$ ('95)]
Mining	110.58
Extraction and transformation of minerals (stones and clay)	29.10
Food products	9.35
Beverages	10.10
Tobacco	0.16
Textiles and clothing industry	15.32
Leather products	1.97
Wood products, except furniture	0.89
Paper and products, printing and publishing	27.52
Petroleum refineries and coal products	8.35
Chemical products	57.97
Rubber products	4.15
Plastic products	3.47
Glass and pottery products	3.50
Production and transformation of metals, metal products	13.25
Machinery, except electrical	0.83
Machinery electrical	1.10
Transport equipment	1.99
Manufacture of furniture, jewelry, musical instruments, others	1.86

A second unification was necessary to compare economic data of several times and places. For the calculations within the industrial sector, all data were transformed into US$ of 1995.
Table 10 lists the industrial water use intensity (WUI) per industrial branch for Germany 1995. The branch specific WUIs were computed with annual data of the industrial gross domestic product (IGDP) per branch and the water used in firms per branch in Germany (Statistisches Bundesamt, 1998, 1999).

5.2.4 Input of industrial gross domestic product (IGDP)

The availability of data of IGDP in Ceará and Piauí is very different. For all municipalities of Ceará branch specific data from 1993 to 1996 exist in the internal database of IPLANCE. Whereas for Piauí, SEPLAN (1997) published the total gross domestic product (GDP) of

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Piauí 1996 and SUDENE (1996a, 1996b) published preliminary data of sectoral GDPs for the three main sectors: agriculture, industry and services for 1995. Neither data of the total GDP per municipality nor the IGDP per municipality do not exist for Piauí.

Branch-specific IGDPs for the all municipalities of Piauí were assigned in three steps:

1) Assuming that Piauí and Ceará have the same firm-specific IGDP per industrial branch, for each municipality of Piauí an IGDP was assigned via the number of firms per branch and an IGDP/firm per branch:

$$IGDP_i = \sum_{b=1}^{19} firms_{b,i} * \frac{IGDP}{firm}_b \qquad \text{(F 5.5)}$$

i: *municipality of Piauí*
b: *industrial branch*
IGDP: *industrial gross domestic product [US$1995]*
firms: *number of firms*
IGDP/firm: *industrial gross domestic product per firm per branch [US$1995/firm], mean value of Ceará*

The IGDPs/firm per branch are average values for the state of Ceará 1995. They were calculated from the number of firms per branch and municipality (IPLANCE, 1997) and the IGDP per branch and municipality (internal data of IPLANCE). This procedure was used, because the number of firms per branch and municipality were the only industrial data available for both states (IPLANCE, 1997; FIEPI, 1991).

2) For those municipalities of Piauí which only have an industrial water use IWUWW but no firms, the total IGDP resulted from the quotient of their IWUWW and an average industrial water use intensity of Piauí ($IWUI_{Piauí}$). The $IWUI_{Piauí}$ was calculated from all municipalities of Piauí having both, IGDP and IWUWW; it's value is 5.442 m^3/1000 US$1995. For comparison: the average IWUI of Ceará is 4.475 m^3/1000US$ and of Germany 15.87 m^3/1000US$.

3) Municipalities of Piauí which neither had firms in 1991 nor industrial water from AGESPISA 1998/99 got the IGDP zero.

Finally, for the computation of industrial water use the following IGDP data per branch per municipality were used: for Ceará the given data by IPLANCE, for Piauí the self-produced IGDP data as described above.

5.2.5 Input data for the scenarios

The important driving force of the industrial water use scenarios is the industrial gross domestic product (IGDP) while all other factors like industrial mix, water use intensity and the fraction of IGDP on total GDP are held constant for the scenarios. The annual IGDP per municipality is calculated from the total GDP per year and municipality and it's percentage of GDP in 1997. The annual changing population multiplied by the annual increasing GDP per

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capita (see Table 9) gives the total GDP per municipality. Driving forces set for one scenario region are used for all municipalities within this region. With NoWUM, structural change of industry could be shown if the industrial mix will be varied. To do this in a sophisticated way, macroeconomic knowledge has to be consulted.

6 Tourism water use

6.1 Method and calculation

The tourism withdrawal water use per municipality is calculated as

$$wd\_tourism[i][m] = tourists[i][m] * stay[i][m] * tourist\_use[i][m] \qquad \text{(F 6.1)}$$

i: *municipality*
m: *month*
wd_tourism: *total tourism withdrawal water use [m³/month] per municipality*
tourists: *number of tourists [p/month] per municipality*
stay: *medium stay of tourists [d] per municipality*
tourist_use: *withdrawal use per tourist [m³/month/p]*

A water use efficiency of 0.2 (USGS, 1998) is used to calculate the tourism consumptive water use out of the tourism withdrawal water use.

6.2 Input data

6.2.1 Input data of the present state

The present number of tourists per "touristic" municipality in Piauí was personally given by the co-director of the tourism agency of Piauí PIEMTUR. Touristic municipalities here means touristic municipalities and municipalities with tourism potential classified by EMBRATUR (1997). For the municipalities of Ceará the number of tourists was combined out of several regional studies on tourism in Ceará. Table 11 lists the combining procedure.

As medium stay of tourists per municipality the given values of 9 days for the Ibiapaba region (SETUR/CE 1998 c), 8 days for the coastal region (SETUR/CE 1997 a) and 5 days for the Cariri region (SETUR/CE 1998 d) and the rest of Ceará (SETUR/CE 1997 c) are used in the simulations. For Piauí the medium values of Ceará are taken over: 8 days for the coastal municipalities and 5 days for the municipalities of the interior.

The water requirement in hotels varies between 300 and 500 l/d/p (Stephenson, 1998). In NoWUM is used a high touristic water requirement of 500 l/d/p in the coastal municipalities reflecting the better hotel infrastructure (swimming pools, irrigation of gardens) and relating activities of tourists (several baths per day). In all other municipalities a water requirement of 300 l/d/tourist is used.

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6.2.2 Input data of the future

For the two reference scenarios we made different assumptions for the number of tourists and the touristic water use, while the medium stay of tourists is used as for the present state. For the "coastal boom scenario" (A) the number of tourists increases with factor 5 towards the present state in the municipalities of the coastal region and the metropolitan area of Fortaleza. In the municipalities of the interior it increases only with factor 3. In the "decentralization scenario" (B) the number of tourists is assumed to increase with factor 3 towards the present state in all municipalities. While for the scenario B the touristic water use is used as in the present state, it differs in scenario A. In the coastal boom scenario A the touristic water use for the municipalities of the regions Teresina, metropolitan area of Fortaleza and the coastal region is set to 500 l/p/d; in all other municipalities to 300 l/p/d. For pilgrims NoWUM uses only 100 l/p/d.

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Table 11: Assessment of number of tourists in municipalities of Ceará 1997/98

Region	Tourists	Source	Distribution in the municipalities
I Ceará total	5.660.483	*7, 8*	It is obvious that in *7* not all pilgrims were counted, because in the estimation of 720.157 tourists/a only 168.517 pilgrims are included and 1.831.483 pilgrims lacking. Consequently, the same number has to be added to the total number of tourists. It rises from 3.829.000 to 5.660.483 tourists per year.
II Fortaleza and from there to other municipalities of Ceará 1997	970.000	*2, 4, 5*	Persons arriving at Fortaleza with any kind of transport (plane, bus, car, etc.) are assumed to stay 5 d in Fortaleza. Following they visit other municipalities (the percentile quota to single municipalities in: *1*). Source *2* includes the monthly division.
III Ibiapaba 1998	117.196	*6*	The number of tourists is equally divided into all of the seven municipalities of the Ibiapaba region. The monthly division of tourists is taken over from the situation in Fortaleza (*2*).
IV Cariri without pilgrims 1998	551.640	*7*	23,4% of the 720.157 tourists in the Cariri region have a religious motivation for their visit. The tourists, except pilgrims, are monthly divided as in Fortaleza (*2*). Single municipalities get the number of tourists according to their number of beds (from: *3*).
V Cariri-pilgrims 1998	2.000.000	*12, 13*	Estimation of pilgrims per year in newspapers. Pilgrims appear only in the month of February, July, September and November. They are distributed to the three municipalities Juazeiro do Norte, Crato and Barbalha according to their number of beds (from: *3*).
VI Canindé average of 97/98	700.000	*11*	This amount of pilgrims appears during the 10 days procession in October.
VII Sum (II up to VI)	4.338.836		
VIII Rest (VII - I)	1.321.726		The rest of tourists is distributed to the touristic municipalities classified by EMBRATUR except Canindé, the seven municipalities of the Ibiapaba and the six municipalities of the Cariri region. For this, the 21 coastal municipalities were weighted with factor 3 and the interior municipalities with factor 1. In case a municipality still got tourists under point II, these tourists are added.

Piauí: 767.200 tourists per year without double appearence in several municipalities like at point II.

1 SETUR/CE,1997 a	*4* SETUR/CE,1998 a	*7* SETUR/CE,1998 d	*10* SEBRAE/CE,1998	*13* Diário do Nordeste,1998 b
2 SETUR/CE,1997 b	*5* SETUR/CE,1998 b	*8* SETUR/CE,1998 e	*11* O Povo,1998	*14* EMBRATUR,1997
3 SETUR/CE,1997 c	*6* SETUR/CE,1998 c	*9* SEBRAE/CE, SETUR,1998	*12* Diário do Nordeste,1998 a	*15* Stephenson, D.,1998

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7 Model input

Most of the parameters are read from one input file each. The data are read into matrixes of size *number of municipalities* and *number of months* or *number of days*. NoWUM needs several input data files:

1. daily values of precipitation per municipality
2. daily values of evapotranspiration per municipality
3. planting data, growing periods and crop coefficients of irrigated crops
4. irrigated areas per crop of one year per municipality
5. numbers of livestock species per municipality
6. total population of one year per month per municipality
7. supplied population of one year per month per municipality
8. monthly water volume supplied by public water supply system per municipality
9. water use efficiency of public water supply system per municipality
10. best guess of industrial water use per municipality
11. industrial gross domestic product per industrial branch per municipality
12. water use intensity per industrial branch (constant for all municipalities)
13. number of tourists per municipality
14. medium stay of tourists per municipality
15. touristic water use per municipality

Some driving forces of the scenarios are given only per scenario region such as population growth, price rates and growth of gross domestic product per capita. They are read from customized input files.

Appendix 1 gives examples for the input data files. Data of input files 1 to 4 are used to calculate the irrigation water use, data of file 5 for livestock water use, data of files 6 to 9 for domestic water use, data of files 10 to 12 for industrial water use and data of files 13 to 15 for tourism water use calculation. For executing NoWUM, all data file names (input and output) are either read from the desktop or from file *input*.

8 Model output

NoWUM computes monthly sectoral and total withdrawal and consumption water use [m³/month] for all municipalities of Ceará and Piauí. Examples of some of the output files are given in Appendix 2:

1. Total withdrawal water use of all sectors per month per municipality
2. Total consumptive water use of all sectors per month per municipality
3. Withdrawal water use of irrigation per month per municipality
4. Consumptive water use of irrigation per month per municipality
5. Withdrawal water use of livestock per month per municipality
6. Consumptive water use of livestock per month per municipality
7. Withdrawal water use of domestic sector per month per municipality
8. Consumptive water use of domestic sector per month per municipality

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9. Withdrawal water use of industrial sector option 1 per month per municipality
10. Consumptive water use of industrial sector option 1 per month per municipality
11. Withdrawal water use of industrial sector option 2 per month per municipality
12. Consumptive water use of industrial sector option 2 per month per municipality
13. Withdrawal water use of tourism sector per month per municipality
14. Consumptive water use of tourism sector per month per municipality

Every sectoral procedure has a query for missing input data. If one parameter is missing, the output file gets in the same position the missing value -9999, too. Besides, a list of missing values is written to a protocol file.

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