Aquastress D2.3.3 - Integrated water balance models for water stress adapted to test sites

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AQUASTRESS

Mitigation of Water Stress through new Approaches to Integrating Management, Technical, Economic and Institutional Instruments

Integrated Project

2.3-3

DELIVERABLE:
INTEGRATED BALANCE MODEL FOR WATER STRESS ADAPTED TO TEST SITES

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Abstract

This report is based on the report Milestone 2.3-1 of the Aquastress project (Schmidt et al, 2005), which presented an inventory of examples of water balance models and gave a list of criteria to characterise hydrological models, and on the report Deliverable 2.3-1 of the Aquastress project (Schmidt et al, 2006), which describes the concept of the water balance model and the structure of the water stress assessment in the domestic, industrial, agricultural and (semi)natural ecosystem sectors. The water balance model (WBM) elaborated within work package 2.3 of the Aquastress project is used to characterise water stress and to identify causes of water stress. For the water balance model the water stress definition of work block 2 has been used (Bauer et al, 2005). The assessment of water stress by the WBM is simplified because it does not incorporate all aspects of water stress which are listed in the definition of Bauer et al., 2005. Thus the WBM does the "simplified water stress assessment" based on water fluxes and water quality, whereas the water stress definition of work block 2 takes also into account the adaptability of the test site to cope with water stress (Sullivan et al, 2007).

The WBM provides a useful framework to characterise simplified water stress at a regional level. In the WBM simplified water stress is assessed in so called "sectors". The industrial, domestic and agricultural sectors comprise calculations of water devoted to human consumption, whereas the environmental sector comprises water needed to sustain the (semi-)natural ecosystems. This text describes the adaptation and application of the water balance model in selected test sites. The water balance model has been developed as a generic tool which has to be modified to meet the characteristics of a test site. The model has not been tested or discussed by local partners or stakeholder although it has been prepared during the last project year and local partners showed interest. Due to the time delay within the project, particularly within the research activities with local partners, and due to the end of work block 2 research activities after the third project year, these activities will not been carried out. The application of the model is based on data being collected by project partners or already available from local partners or stakeholder. The water balance model is applied to two test sites (Morocco and Bulgaria). It has not been applied to all test sites because of data availability, the interest and co-operation of local partners, and the test sites characteristics. Both test sites cover all relevant sectors of the WBM. The WBM has been discussed with local partners in Morocco and integrated in the JWT activities. The application of the water balance model shows that the water balance model is able to represent the water stress situations in the test sites. Together with users of the water balance model it enables to structure discussions about causes of water stress and potential mitigation options.

1. Background information

1.1 Introduction

The major task of the Water Balance Model (WBM) is to express water stress by estimating the water demand of each of the five sectors and to compare water supply with water demand at each sector. In order to do so, the WBM characterises relevant sub-units within the main water functional unit, and establishes inputs and outputs to and from each sub-unit, and models their interaction, i.e. water flows between sub-units in order to express water stress. The main idea behind the model structure is to provide a framework in which users can visualise the interactions of the water system components (at which water users and administrators participate) and obtain realistic outcomes from alternative scenarios showing water stress. According to these objectives, sub-units must be characterised by finding "natural" hydrological functional boundaries within the system (e.g. water in soil, precipitation) and/or socially meaningful sub-units that intervene in the decision making process (e.g. water provided by a central government vs. water obtained by individual farmers, water allocated to livestock).

Limitations and problems arising while coming up with a water balance either for the hydrological unit or for a socially meaningful unit are described in Schmidt et al, 2006. The model is applied to two specific regions, the test sites, and sub-units are defined according to the functional characteristics of these test sites in Morocco and Bulgaria. Given the particular flexibility of the software Umberto, sub-units can be added, deleted or changed according to the needs of each specific area. The model is non-spatially explicit, which means that the spatial relationship between sub-units is not taken into account. The time dimension is also non-explicitly considered (i.e. the software does not take into account events from a previous time step), however the model user can manually enter initial conditions at each time step calculation.

1.2 Definitions

The following definitions are used:

- **Water resources** are defined by the amount of water flowing in rivers and in aquifers, originating either from local precipitation or by water received from neighbouring areas in transboundary rivers and aquifers (which equals to "renewable water resources" in EEA, 1999). In the WBM additionally artificial water imports (diversions, desalination, etc.) are included.
- **Water abstraction** is the portion of the water resources that is physically removed from its natural site of occurrence (EEA, 1999).
- **Water supply** is the portion of abstracted water supplied to the domestic, agricultural, tourist and industrial sectors. The water supply does not automatically include water losses. In the WBM water losses during conveyance and distribution of water include evapotranspiration and leakage.
- **Water losses** (non-process depletion) is the amount of water removed from water resources which render unavailable for further use, e.g. water that evaporates from irrigation canals or seepage in a supply network due to leaks.
- **Water consumption** (process depletion) is the portion of the supplied water that remains in the sectors, e.g. water in agricultural products or water in industrial products. Benefits are derived from the use of this water.
- **Return water** is the fraction of water abstraction which is used and reintroduced into the natural water cycle, e.g. as discharge. Depending on the quality and quantity of the water the return water might affect the environment.

- **Committed water** is defined as the portion of water reserved for more than one use (Molden, 1997). Thus the definition of "committed water" requires that at least two water uses are defined and that water is allocated between these two water uses.
- **Sector water supply** is the amount of water supplied to a single sector, which is intended to be used exclusively by that sector and not derived to another one. It is calculated by taking into account committed water as well as water losses of the water supply network. To calculate the amount of a sector water supply the amount of water abstracted from the water resources has to be computed, and the following subtracted: amount of water allocated to other sectors, to upstream water users, losses of the supply network, and the reuse of water within a sector.
- **Water demand** is defined as the volume of water requested by users to satisfy their needs (EEA, 1999). It does not automatically equal the amount of used water or the amount of supplied water. In the Aquastress project "user" is not restricted to human beings. The amount of required water is calculated for each sector. The water demand is a theoretical amount of water based on the literature, statistical data and/or on local expertise on water needs of different sectors.

1.3 Simplified water stress assessment

The WBM assesses water stress based on water flows and thus, it is simpler than the assessment of water stress in the water stress matrix of work block 2 (compare Bauer et al, 2005). Water stress in a sector occurs if the water demand of the sector is higher than the sector water supply. Water stress increases if less water is available (e.g. because upstream water uses increase water abstraction) or if an increasing amount of water is required to fulfil the needs of a sector (e.g. because different crop pattern require more irrigation water; or a higher standard of living increases water demand of the domestic sector). Within a test site, water stress is calculated on monthly data for the following sectors: domestic, agricultural, industrial (including tourist) and (semi-) natural ecosystem. The assessment of water stress is based on the assumption that the water demand of a sector does not correspond to the amount of water supplied to the sector.

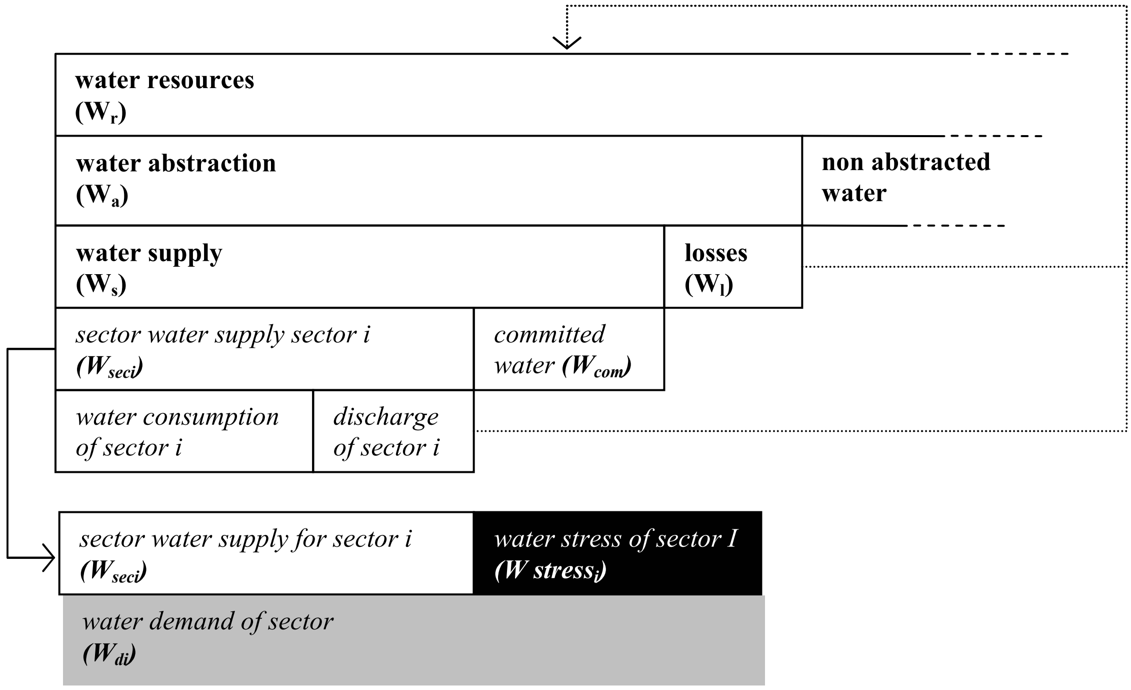


Figure 1: Simplified water stress assessment in the Water Balance Model

The supplied water of the domestic, industrial, tourist and agricultural sector is calculated using the amount of abstracted water and subtracting water losses and water committed to other sectors (for more details compare Schmidt et al, 2006).

Sector water supply: $W_{\sec i} = W_a - W_l - W_{com}$

In general the difference between sector water supply and water demand will indicate the severity of water stress in the sector: the larger the gap between water demand and sector water supply, the higher the water stress (compare Figure 1). In order to avoid an excessive influence of one sector's stress on the overall stress calculation, the results for single sectors are normalised. A water stress result of 40% means that only 60% of the water demand is satisfied by supplied water. Increasing numbers indicate increasing water stress and vice versa. A sector water stress is expressed as:

Sector water stress: $W_{stressi} = W_{di} - \frac{W_{\sec i}}{W_{di}}$

2. Application and adaptation of the water balance model in the Bulgaria test site

2.1 Introduction

According to Apostolaki & Assimacopoulos (2006) the the water stress situation in the test site is characterised as follows: „The Upper Iskar basin is situated in the mountain and semi-mountain area with numerous water sources, reservoirs and favourable climate conditions predestining a good development of the water sector. However, the water situation in the Test Site is strongly linked to the determined water stress issues breeding regularly or constantly different water problems with impacts on the social-economic life of the region, sometimes causing conflicts over water uses and among water users in the state or/and private institutions. Irregular surface water runoff distribution throughout the year combined with alternation of periodic droughts and rare but severe inundations put to ordeal and test the normal functioning of the water supply infrastructure.

Hence, the appearance of conflicts between water uses in different water sectors as industry, agriculture or drinking water supply has a regular character. The intensive process of rapid urbanization, population growth and tourism expansion, results in increased water demands without availably of new water resources in the Iskar basin. To the water resources troubles must be added some significant water pollution problems influencing negatively on the environment and the water ecosystems at several places in the basin and posing numerous technical and technological issues. The industrial wastewaters and wastes but noncontrolled disposals of domestic and municipal waters as well are the main polluters of the river system. The presence of a big city as the capital Sofia with an old pipelines network, high percentage of drinking water losses in water supply network and sometimes worsened water quality is among the problems determining negative aspects of the water situation in the Test Site. Finally the issues of the bad water consumption practices, the improvement of the water management and the inter-institutional relationships are pending before the decision making authorities and the all informal groups in concern.“

2.2 Sectorial water demand and water supply

For details about the Bulgarian test site, several reports are available at the Aquastress website. For this deliverable mainly the following reports have been used: Inman, D. et al, 2006 and Apostolaki & Assimacopoulos, 2006. The water balance for the Bulgarian test site focuses on the allocation of water resources to the domestic, industrial and semi-natural ecosystem sectors (Figure 2). Although the agricultural sector is included in the model, it is represented by a simple structure due to lack of adequate information. Furthermore, as in the case of the entire Danube basin, the agricultural sector plays a minor role in the test site (Apostolaki & Assimacopoulos, 2006). Besides estimating water stress for each sector, the model also calculates water stress downstream for the entire test site to functionally integrate it to adjacent areas.The water balance is established on a yearly basis but could be changed into monthly or daily basis.

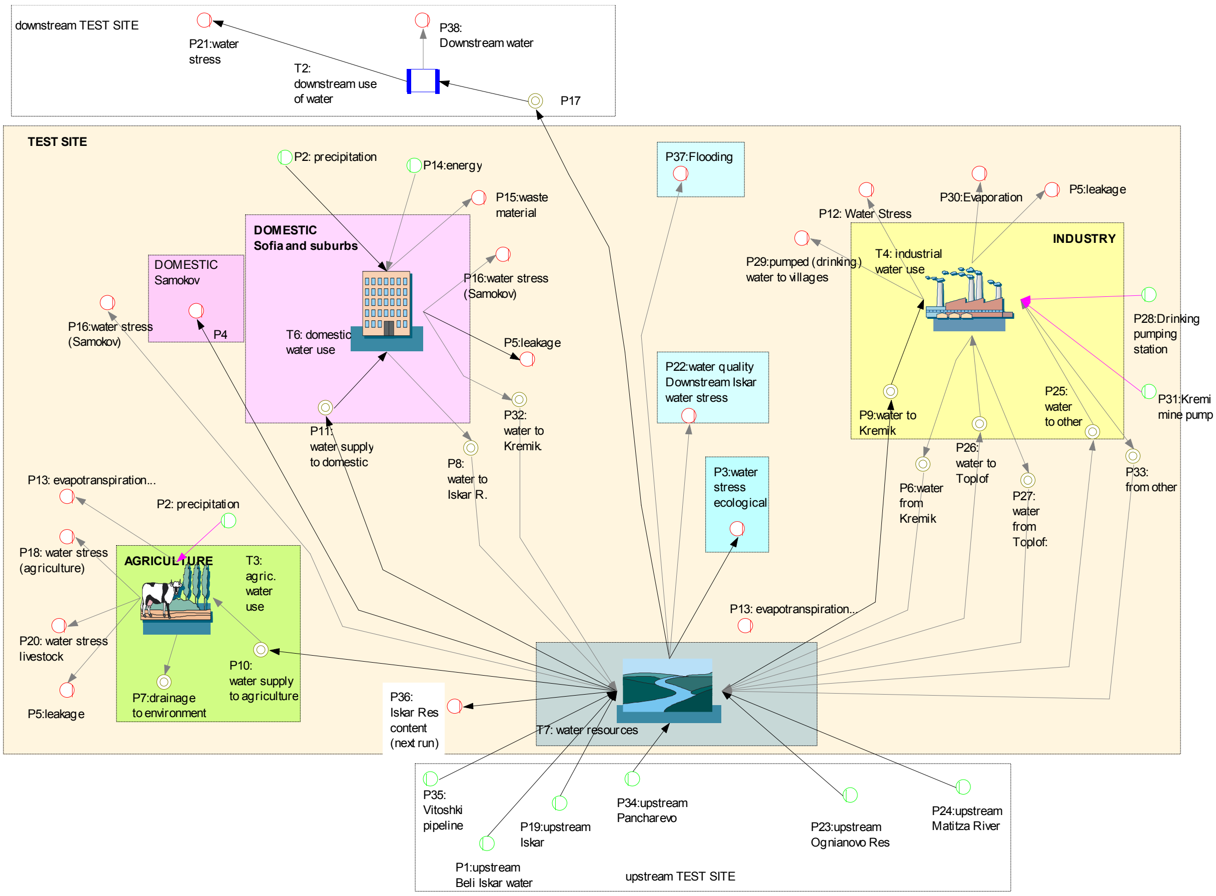


Figure 2: **Main structure of the Water Balance Model for the Bulgarian test site**

As inputs the following water resources have been taken into consideration: Vitoshki pipeline, upstream Beli Iskar reservoir, upstream Pancharevo reservoir, upstream Ognianovo reservoir and upstream Matitza in Mm^3/yr. For the agricultural and domestic sector precipitation was also included, and for the Kremikovzi mine pumping and a drinking pumping station were added. Figure 3 gives an overview of the interrelationship between natural water resources and the sectors showing also the spatial structure of the test site.

Although data on groundwater is available on the level of the Danuber basin district it is not sufficient to run a model on the test site level. For this reason groundwater is not included in the WBM.

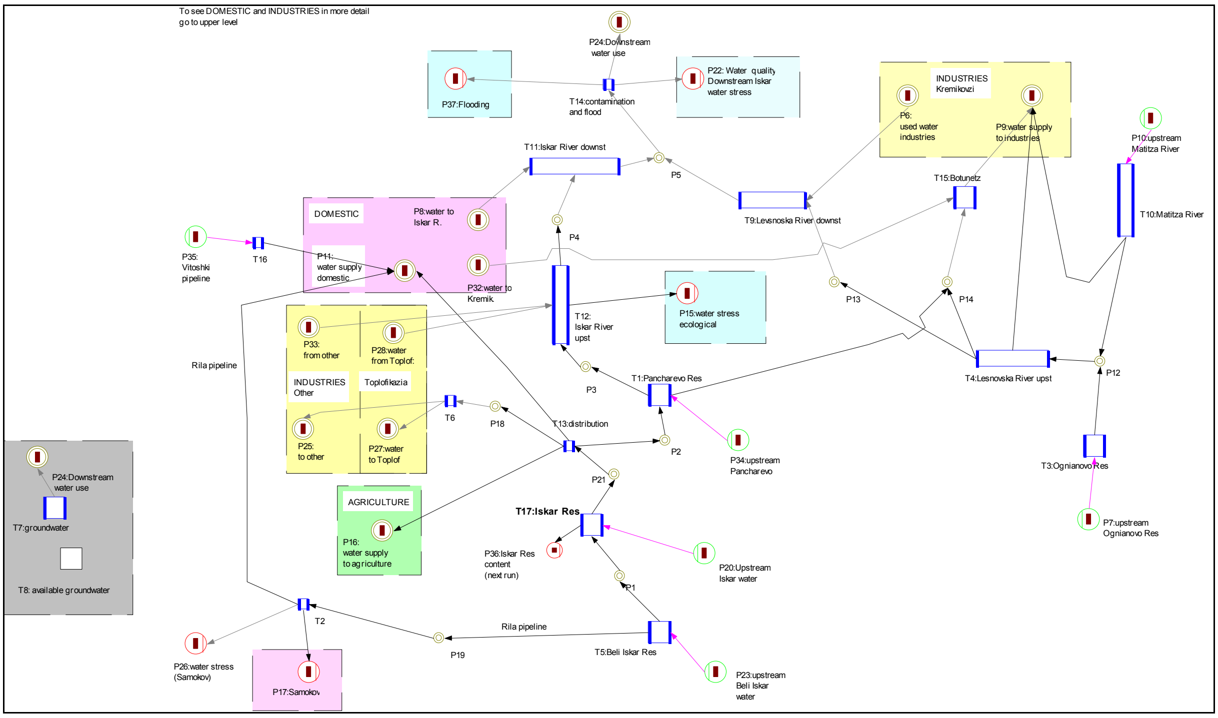


Figure 3: **Water resources and sectors of the Bulgarian test site**

From the Belli Iskar Reservoir a small percentage of the water goes to Samokov through Rila Pipeline. The rest goes to the Iskar Reservoir. The Iskar reservoir acts as the main water regulation unit of the entire region, and its output is based on the following rules: The reservoir balance is based on the input from upstream sources plus its current content. The reservoir has a maximum capacity, which in case it is exceeded, the excess is discharged immediately. If the excess does not exceed the already set amount of water to be supplied from the reservoir, then an additional amount of water is output to reach this quota. If input from upstream sources plus the reservoir's current content is less than the amount set to be supplied, then all the input is discharged, and no water is left in the reservoir. Alternatively, if some water remains, it is used for the next model run. The iskar reservoir output is sent to a distribution point with the following prorities: first, a fixed supply to Sofia; second, a fixed supply tothe agricultural sector; third, supply to Sofia industries; and lastly, whatever is left goes downstream to Pancharevo reservoir. From Pancharevo reservoir a portion goes to Kremikovtzi industrial plant and the rest is delivered downstream Iskar river to a river section called Iskar River Upstream. This river section has a minimum water amount demand to perform its ecological functions. If this requirement is not met, water stress results. Output from this river section goes to Iskar River Downstream, which also receives the water output from the Sofia water system.

The Iskar river downstream also receives water from the Lesnovska river basin, whose waters in turn come from the Matitza river and the Ognianovo reservoir. The Levsnovska river basin provides most of the water allocated to the Kremikovtzi industrial plant.

Besides the Iskar River Upstream, there are two additional points in the test site model at which water stress in calculated. Both occur at the lower end, close to the output of the entire test site: 1) a water stress due to a deficient or excessive amount of water, which results in water stress or flood, respectively; and 2) a water stress due to poor water quality. This latter is calculated as the amount of water that would be needed to take the pollutant concentrations to permitted levels.

For the estimation of the domestic water demand the default values are given on a daily basis but transferred to a yearly basis to match with the water resources balance. The following parameters are used:

- number of days of calculation (default=365)
- wc water use (l*cap/day)
- bathroom water use (l*cap/day)
- washing machine water use (l*cap/day)
- dish washer water use (l*cap/day)
- car washing water use (l*cap/day)
- garden water use (l/m^2*day)
- water losses due to urban system leakage (%)
- Sofia's center vs. suburb distribution of population (%)

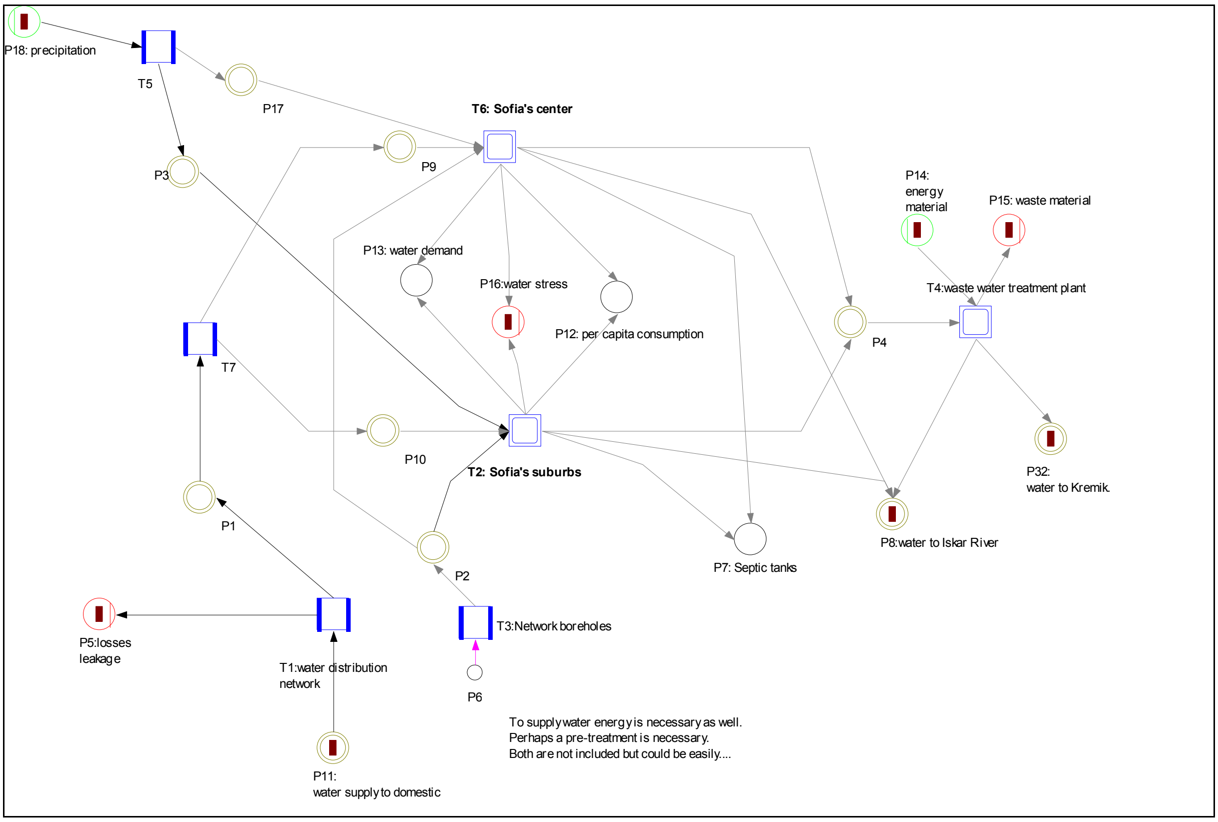


Figure 4: Water distribution in the domestic sector of the Bulgarian test site

The WBM allows distinguishing different standards of living. For the Bulgarian test site, Sofia center and Sofia suburb settlement areas are defined (Figure 4). It is possible to define additional settlement areas or combine both in one settlement area depending on the stakeholders needs. For the Sofia center and suburb population three different standards of living could be defined by the stakeholder to account for different water use characteristics (for more details about the calculation of the domestic water demand, see Schmidt et al, 2006). Additionally the percentage of households connected to septic tanks as well as the percentage of households connected to the sewage is considered. It is assumed that in general 25 l per capita and day are used for personal hygiene (21 l) and for drinking and cooking (4 l).

The industrial water demand is difficult to calculate. In cooperation with project partners the water demand for the sinter plant in Kremikovtzi and the Toplofikazia Heating is taken into account, and room is left for “other” industrial plants.

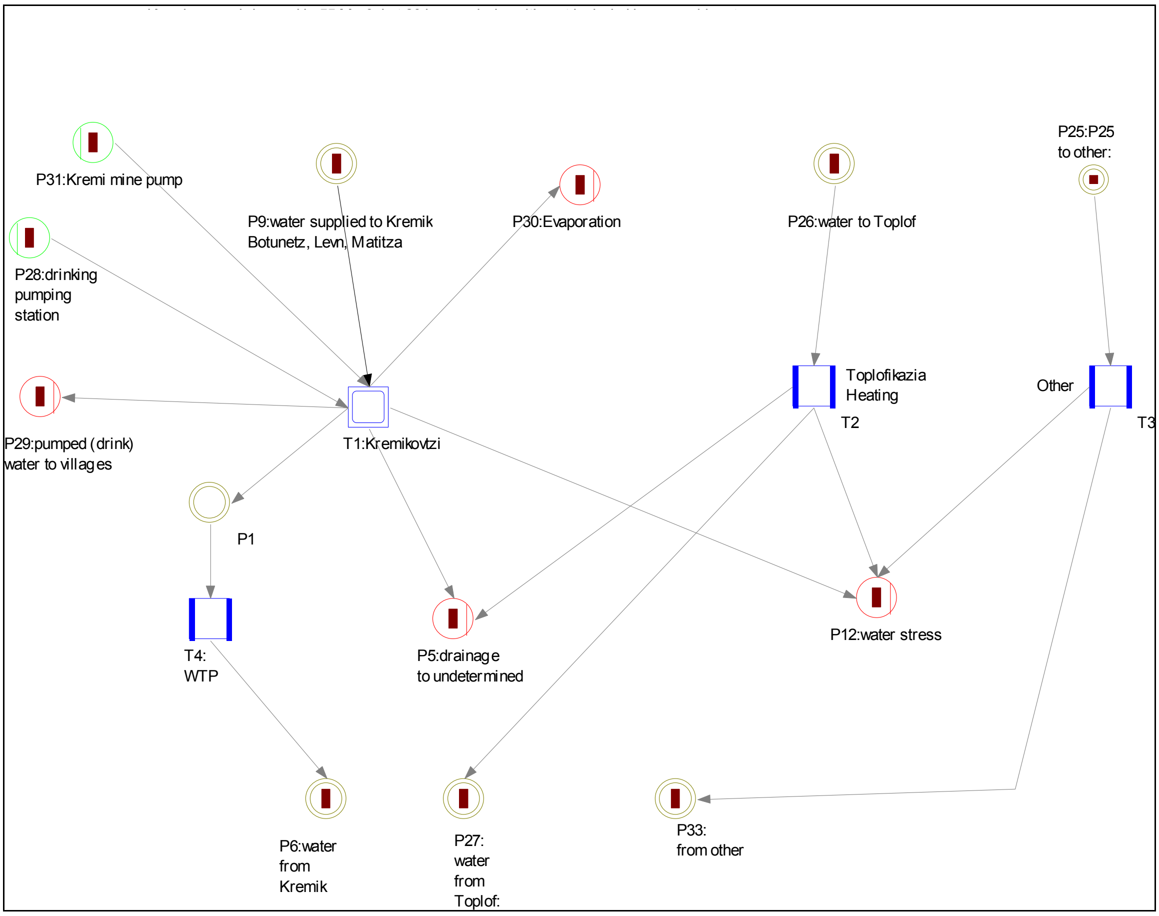


Figure 5: Water distribution in the industrial sector of the Bulgarian test site

For the calculation of the water demand of the sinter plant, there is a recycling water amount of 20 Mm^3/y considered. If enough water is left, the rest of the water is allocated to the villages. While supplying it 10% of the water is lost by drainage as well as to evaporation. Water stress is calculated for the industrial plants as well as for the villages.

For the agricultural sector calculation an area of 10.000 ha is defined. The precipitation as well as losses by percolation is considered. For evapotranspiration it is assumed to be about 700 mm per year acording to the calculation of Knight & Stanev (1996).

The metallurgical plant Kremikovtzi was designed to be supplied with water from Pancharevo lake only. According to the project, the maximum rate of consumption of water was 110 million m^3 per year. After the water crisis in 1980-1985 alternative water sources - Pump Station (PS) “Lesnovska”, PS “Kazichane1”,PS “Kazi-chane 2”, PS “Dolni Bogrov”, ballasts were built. The used water from all resources was about 90 million m^3/year until 1995-1996, where another water crisis happened. Then, several measures were undertaken to reduce the consumption of fresh water. As a result, for the period 1997-2002, the necessary fresh industrial water was decreased to 50-60 milllion m^3. The company uses water from both Sofiisja voda Ltd and own water sources. Several measures were undertaken to reduce the used fresh water.

In case of a dry year, the permits consider article 50 of the Water Law, which establishes the following priorities: household, health care, irrigation, and others (including industry).

2.3 Model runs

The initial screening on the opinion of the stakeholders about the water stress in the region outlined the following issues (see also: Apostolaki & Assimacopoulos, 2006):

- irregular surface water run off distribution throughout the year
- alternation of periodic drought and rare but severe floods
- conflicts between water use for industry, agriculture and drinking water supply
- increased urbanisation, population growth and tourism, resulting in increasing water demand
- illegal deforestation resulting in reduced amounts of available water and increased run off irregularity
- non-controlled disposal of domestic and industrial WBMewaters and WBMes
- 20% of drinking water for Sofia not purified
- high turbidity of drinking water in spring and autumn;
- old pipelines, worsened water quality;
- high percentage of drinking water losses in water supply network
- bad management of water resources in Upper Iskar region.

The local partners showed interest in applying the water balance model in the test site. The WBM is set up in a way that it allows to calculate water balances for different scenarios in order to discuss:

- which driving forces are most important and
- which cause of water stress could be addressed by a given mitigation option and
- what the effects of mitigation options in the water system are.

In order to define scenarios the driving forces could be used already defined by the stakeholder (Apostolaki & Assimacopoulos, 2006). The most important natural driving force is climate, whose variations cause alternations of dry and wet years. Besides the lack of enough drinking water the bad water quality has to be addressed. The country had not been prepared to manage such intensive rainfalls. Considering the irregular surface run-off throughout the seasons, Iskar reservoir was built. The existence of only one large water source was considered as another driver of the water stress. It makes the water supply system of Sofia non-reliable in case of failures or droughts, and the allocation to several water users is difficult. In the case of big damages or collapse of this unique big water source, automatically the life in the city would be in danger.

- The WBM could calculate different allocation rules between domestic, industrial and agricultural sector. Additionally the impact of changes in the use of water upstream could be taken into account.

The next two drivers are "former state water policies" and "socio-economic development of the capital in the transition period". Although both cause similar pressure on the water scene, their characteristics are different enough to be considered separately. The first driver combines all the negative aspects inherited from the centralized system period of the country (which ended in 1989). The second one combines the boom of the construction in the capital and suburbs due to an extraordinary growth of the Sofia population as a result of intensive inmigration during the last years due to industrial developmen. As a whole, the economical importance of the capital increased comparing to other parts of the country. The strongest pressure of these two drivers is on the user culture. Because of the previous low water price, several generations grew with no water concern. The water wasteful practices continue to the present: water losses from the non functioning appliances, cooling of beer and watermelons with water, etc. The user behaviour determines higher water consumption and results in higher expenses per capita.

- The WBM could calculate scenarios which try to estimate the effect of changes in the use of water in the domestic sector. Both, technical solutions as well as changes in the current habits of people could be included.

The state of the infrastructure is a consequence both from the former state water policy and the transition period development. The lack of investment policies during the two periods brought the infrastructure to very defficient conditions, which results in high water leakages and often water supply interruptions for repairing. This produces discomfort and increases the water per capita expenses.

- The WBM could calculate the effect of improving the water supply network and estimate its effect on water stress in the domestic sector.

Additionally, the defficient water quality of the river after Sofia causes water stress downstream. It is a result of two drivers. The old existing wastewater treatment plants were not maintained during the transition period. Besides, in the past, many industries discharged non-treated effluents. More recently, new legislation was adopted with stricter requirement for the discharge quality into the sewer systems and water bodies. The upgrade of the old WWTPs and building of new ones is needed to recover the natural river ecosystem after Sofia. Despite, some improvement in the water quality (oxygen regime, heavy metals and oils) in the last years, the pollution into the Iskar river system (mainstream and several tributaries) after the capital remains one of the biggest environmental problems in the region.

- The WBM could calculate the effect on water stress by upgrading the waste water treatment plants in the test site.

3. Application and adaptation of the water balance model in the Morocco test site

3.1 Introduction and model description

For details about the Morocco test site, see reports available on the Aquastress website. For this deliverable the reports have been used which are available on the project web site and reports provided by local partners at the beginning of the project.

For the Morocco test site the water balance model focuses on the water stress of the agricultural sector for the Tadla irrigation perimeter, an area devoted mostly to grow crops, which is mostly fed by surface water from the Oum Er-Rbia River. Surface water is distributed to farmers through an extensive net of irrigation canals. This surface water supply to Tadla, called the collective irrigation system (Figure 6), is not modelled but obtained from available data, or supply values are created to produce alternative management scenarios. The water available for agricultural purposes comes from the amount received from the collective irrigation system (after deducing losses from distribution deficiencies), from individual farmer pumping, from precipitation and from the water stored in soil from the previous time period. Water is distributed to both livestock and crops based on an a priori decision of what percentage of the available water is to be allocated to each one. Livestock water need is estimated using standard water requirements and information available for Tadla. Optionally, water for livestock can also be abstracted by pumping. Livestock water stress is then computed as the difference between water need and water allocated. A portion o the water allocated to crops is subtracted as a consequence of water loss due to irrigation system ineficiencies.

Crop water need is calculated using a model subsystem called "Crop demand calculation" (figure 6). In this subsystem crop water demand is calculated assuming that the water needed to sustain crop production should equal the water lost by crop evapotranspiration. Evapotranspiration is computed for individual crops as a function of climate (potential evapotranspiration) and crop characteristics (crop evapotranspiration coefficient, Kc). Each crop type (e.g. cereal, alfalfa, etc.) is represented by a module at which the monthly reference evapotranspiration, Et0, is multiplied by the monthly crop evaporation coefficient, Kc, to estimate the amount of real evapotranspiration, Et. Et is multiplied by the total area of that particular crop at the corresponding month to calculate Et on a volume basis.

Monthly root depth of each crop, soil water field capacity and wilting point are used to calculate the volume of usable water for each crop, also called soil capacity. Actively cultivated area for each crop at each month is also computed here. Crop water stress is then computed by adding together the irrigation water that reaches the plots, the water stored in soil from the previous month, precipitation and evapotranspiration. Water stress is calculated for the entire Tadla irrigation perimeter area on a monthly basis. However, by modifying the corresponding parameters, such as total surface area, or the time scale of climate data, calculations can be done for a smaller area at different time units. The volume of water that exceeds the soil capacity is lost to ground water, and all the available water is consumed by evapotranspiration, the remaining amount is divided by four (to account for only the last week of the month) and entered as water input in next month's calculation.

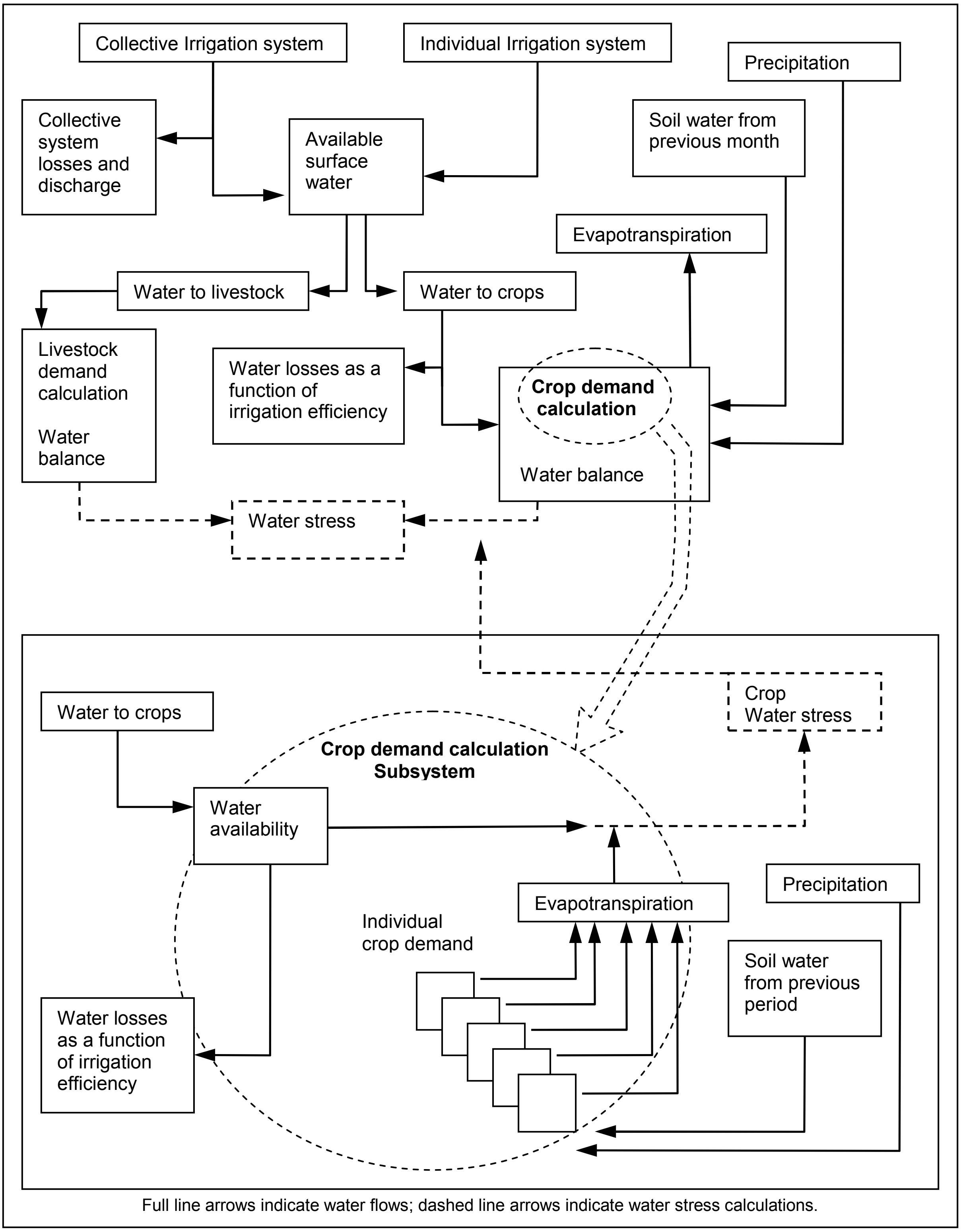


Figure 6: Water balance model structure for the Moroccon test site

3.2 Model testing

To assess the adequacy of the crop water demand calculation subsystem, a comparison of WBM with two widely available crop irrigation models, Cropwat and Budget, was carried out. The crop demand subsystem has a particular relevance for the Tadla case study because agriculture has by far the highest impact on water use, whereas domestic and industrial water use is relatively low. Other agricultural activities, such as cattle raising or forestry, are also relatively unimportant.

Cropwat (for Windows, version 4.3; FAO1992) and Budget (version 6.0, 2004; Raes 2005) are crop water requirement calculation programs that use climate and soil data, and specific crop characteristics to calculate soil water balance on a daily basis for a given period of time. Climate is mostly determined by reference evapotranspiration (commonly known as Et0; Allen et al. 1998) and effective precipitation (frequently estimated as a fraction of total precipitation). Soil characteristics are wilting point and field capacity, which are in turn determined by standard soil types. Crop characteristics include crop evapotranspiration coefficient (commonly known as Kc; Allen et al. 1998) at each growing stage, root depth and soil water allowable depletion.

For the comparison, Cropwat, Budget and the WBM models were run for the main five crop types cultivated in the Tadla irrigation perimeter: alfalfa, cereal (mostly wheat), sugar beet, orchard trees (mostly citrus) and vegetables. Irrigation water requirement for each and all crops was calculated for the entire Tadla area for a year at a time.

The procedure to calculate water requirement was similar for the three models. First, climate data was entered on a monthly basis. Then the crop characteristics were entered, which consisted of: Kc at different crop growth stages and the duration of each stage, day of planting, and initial and maximum root depth. The way in which Kc is entered varies among models. For example, unlike Cropwat, Budget does not allow to enter directly initial growth stage Kc, which is set by bare soil parameters. In contrast, in WBM Kc is entered at each month. For this reason, even though Kc values were initially taken from technical reports and experts from Tadla, they finally needed to be adjusted to the Budget model, which has the least flexibility in that respect (Table 1). Soil allowable depletion is also differently considered in all models. Budget accepts only one value, Cropwat, a value for each growth stage, and WBM a value per month. Root depth was taken from Tadla reports, and soil allowable depletion from each crop was adapted from Allen et al. 1998.

Soil type in Budget was set to loam, with one soil layer and no surface runoff. In Cropwat, was set to loam, with 150 mm/m total available soil moisture (to equal the difference between 350 mm/m and 200 mm/m, the field capacity and wilting point used in WBM, respectively,), and an initial soil moisture depletion of 100% of the total available soil moisture.

The main objective of the model comparison was to check first, if the results in terms of water requirements were comparable between WBM and the other two widely used models; and second, if the WBM model showed a similar sensitivity than the other two models to changes in climate conditions. For this, two extreme years in terms of potential evapotranspiration (low: 1990, high: 1984) were used from weather station records in Tadla (Table 2). In both cases, precipitation from the year 2002, a relatively wet year, was used and an effective precipitation of 85 % of the total precipitation was chosen.

Table 1: Crop parameters and characteristics

Crop	Alfalfa	Cereal	Sugar beet	Orchard trees	Vegetables
Initial Kc	0.4	0.5	0.2	0.64	0.4
Mid season Kc	1.15	1.1	1.1	0.72	1.0
Late season Kc	1.15	0.5	0.5	0.64	0.85
Growing season period	1 Sep-31 Ago	1 Nov-30 Apr	1 Oct-30 Jun	1 Jan-31 Dec	1 Sep-28 Feb 1 Mar-31 Ago
Rooting depth (max-min, m)	1.2	0.3-1.0	0.3-1.0	1.5	0.5
Soil allowable depletion	0.55	0.60-0.90	0.55	0.60	0.35
Crop area in Tadla [%]	30	43	6	18	3

Table 2: Climate used in the simulations (quantities are in mm)

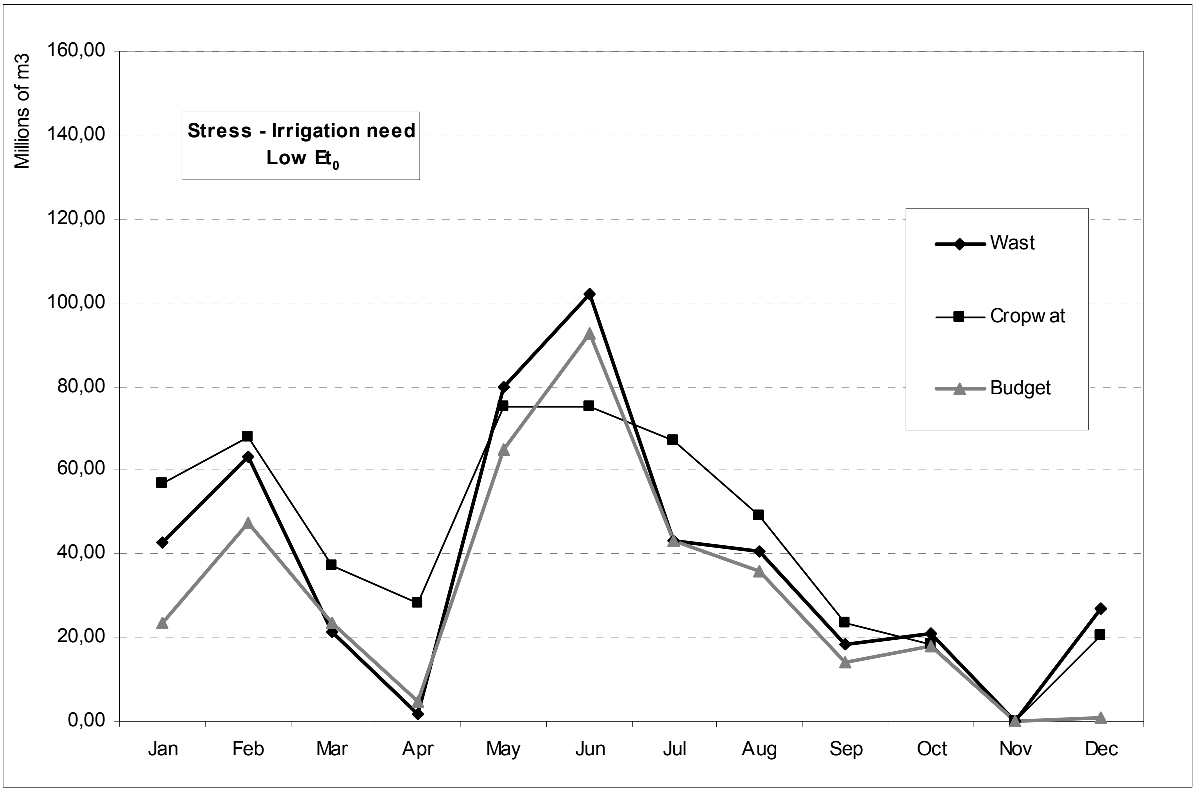
Month	Low Et_0 (yr 1990)	High Et_0 (yr 1984)	High precipitation (yr 2002)	Low precipitation (yr 2001)
J	42.37	41.57	0.00	55.37
F	68.85	50.30	9.15	3.05
M	91.52	70.30	60.70	12.19
A	99.97	116.66	82.80	0.00
M	152.80	105.66	12.19	1.02
J	173.41	181.98	0.00	0.25
J	75.66	266.20	0.00	0.00
A	71.87	206.16	0.25	0.00
S	64.59	167.21	1.78	1.25
O	61.41	113.38	1.52	0.25
N	55.06	60.63	147.87	6.35
D	54.60	50.05	26.93	62.22
Total	1012.11	1430.10	343.15	141.96

Cropwat calculates daily crop water requirement (CWR) multiplying the reference evapotranspiration (Et0) by the crop factor (Kc) and crop irrigation requirement (IR) is calculated by subtracting average daily effective precipitation from CWR (FAO 1992). Budget calculates daily net irrigation need (IN) as the water that needs to be added to keep the water soil content within the readily available soil water (RAW) in order to avoid stress (Raes 2005). RAW is a function of crop's soil allowable depletion (Table 1). Budget estimates soil evaporation and crop transpiration separately to obtain an estimate the actual crop evapotranspiration, which, similarly to Cropwat, it is subtracted from effective precipitation to determine the irrigation need.

Estimates in mm of water needs from Cropwat and Budget for each crop were translated into volume of water per month for the entire Tadla area (1130 km2) to match the WBM outputs. To that end, the water requirement from each crop was multiplied by the percent Tadla area it occupies (Table 1) to calculate the contribution of a particular crop to the overall water requirement. The assumption was that in the months a crop is not present (e.g. cereal in June) the percent of the area that corresponds to this crop is left unused, resulting in a reduced total cultivation area.

As a method to test the relative sensitivity of each model to different climate conditions, a two-way ANOVA test was run (compare Table 3). The ANOVA test could determine, first, whether output differences between monthly Et0 and between the models were statistically significant, and second, which of these two variables showed more differences. The assumption was that if WBM is able to perform reasonably well, it should produce outputs similar enough to other model's outputs to show no significant differences. The two Et0 years and the three models were entered as factors, water need as the dependent variable, and each month was treated as a replicate. Since months of the year represent a time series, there were reasons to suspect that the test assumption of lack of independence between samples could be violated. For this reason, the mean of each group was plotted against the error of each sample, and visually analyzed for evident trends or patterns in the error distribution.

Results indicate that in general all models performed very similarly. There was always higher water need during the dry months, April through September, which was significantly higher during the high Et0 year (Figure 7). In some months Cropwat showed less extreme values of irrigation need than WBM or Budget. The error plots (not shown) showed no specific pattern, suggesting that there were no obvious reasons to believe that the assumption of independence was violated. The F statistic value was in all cases lower than the critical F value (Table 3) and the P-value higher than the 0.05 level. High and low Et0 years showed a P-value closer to the 0.05 level indicating that the Et0 differences were almost statistically significant. This was expected, since the climate years were selected to observe the model's performances at extreme Et0. In contrast, the substantially low F statistic and the relatively high P-value of the "model" factor showed that none of the models had any difference in their outputs, indicating a very similar performance.



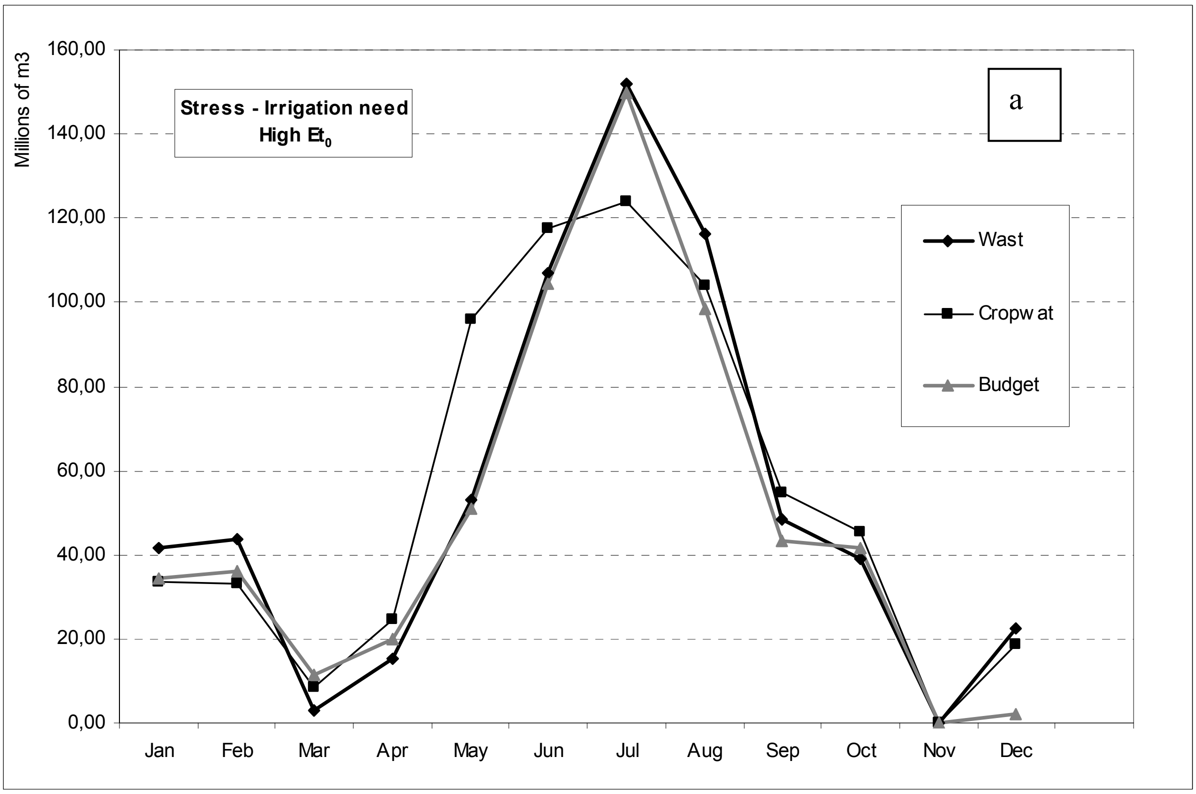


Figure 7: Water stress results of the test models

Table 3: ANOVA results

Source	SS	df	MS	F	P-value	F crit.
Evapotranspiration year	4.17 $\times10^{15}$	1	4.17 $\times10^{15}$	2.90	0.093	3.99
Models	1.01 $\times10^{15}$	2	0.51 $\times10^{15}$	0.35	0.705	3.14
Interaction	0.14 $\times10^{15}$	2	0.073 $\times10^{15}$	0.05	0.951	3.14
Error	95.0 $\times10^{15}$	66	1.44 $\times10^{15}$			
Total	100.0 $\times10^{15}$	71				

3.3 Water case scenarios - Water stress and the effect of irrigation

To gain more insight on the behaviour of the WBM model, water stress was calculated using two scenarios corresponding to a wetter and a dryer year. Actual precipitation data from the Tadla region was used to produce probable scenarios. From the records provided, two contrasting years, 2001 and 2002 were chosen (Table 2).

Since out of the two Tadla subdivisions Beni Moussa presented some inaccuracies, only records from Beni Amir were used as representing the entire Tadla perimeter. Total surface irrigation for Tadla from the same two years was also available. Et0 only for the year 2001, as reported by some reports, was used in both simulations, with the idea of keeping one climatic variable fixed. In the case of surface irrigation, the actual amount of water that effectively reaches the root zone is strongly determined by the efficiency of the irrigation method applied. For that reason, irrigation efficiency of commonly used techniques in Tadla, and the extent to which these techniques are applied to each crop were included in the simulations (Table 4).

Table 4: Irrigation efficiency

Irrigation method	Micro irrigation	Pivot	Robta	Robta improved
Irrigation efficiency [% of total water provided]	90	90	50	75
Crop irrigation method [% of area using a given irrigation method]				
Alfalfa	-	-	100	-
Cereal	-	10	90	-
Sugar beet	-	15	85	-
Orchard trees	100	-	-	-
Vegetables	-	-	-	100

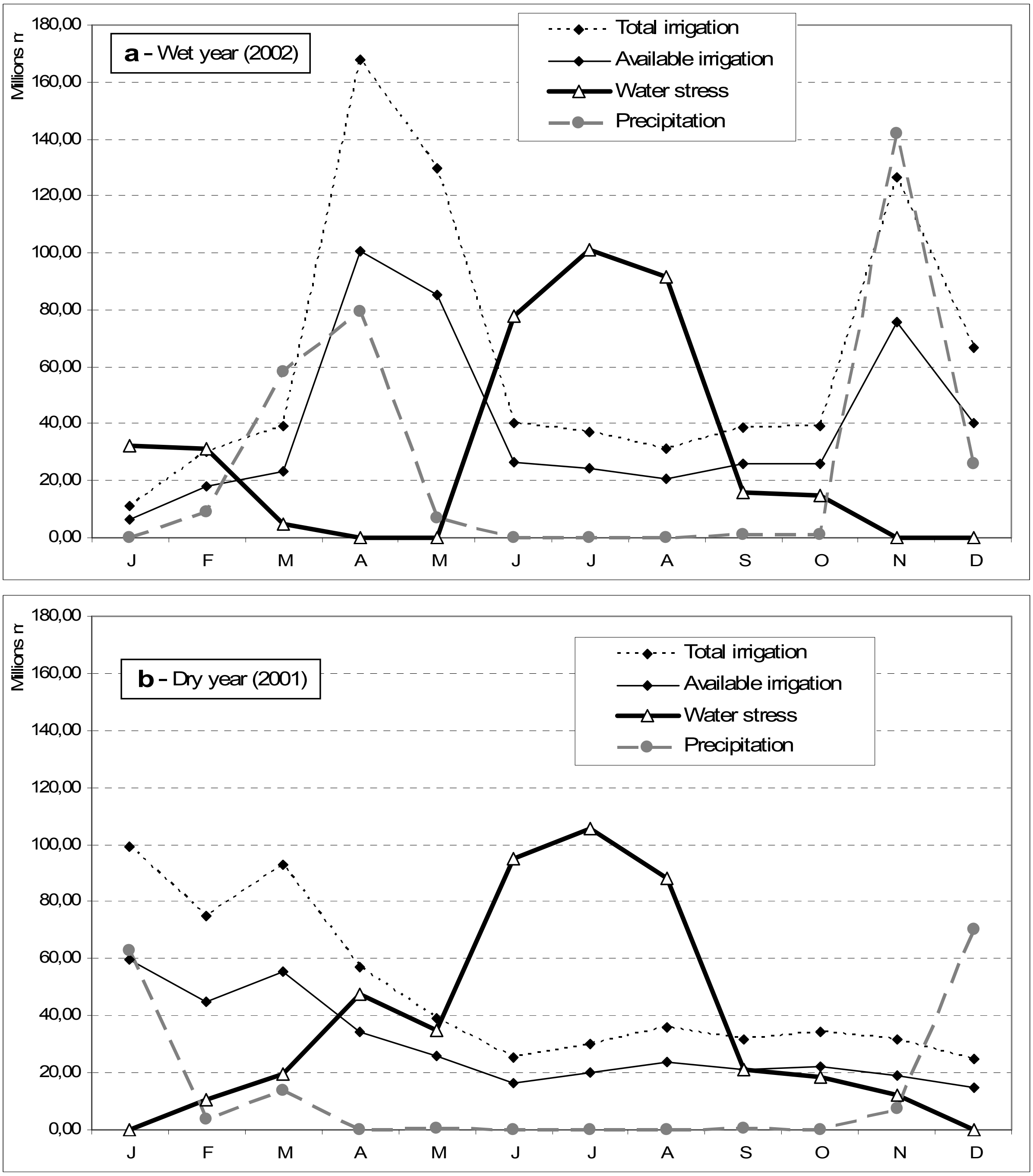


Figure 8: Effect of irrigation on water stress

Figure 7 gives an overview on the water balance model water stress calculation for a wetter and a dryer year (2002 and 2001) in Tadla. Available irrigation water was calculated by estimating water losses due to reduced efficiency of the currently used irrigation techniques. Before commenting on the results of the modelling exercise, there are some interesting patterns that emerge out of the data used, independently of the model. One example of the latter is the monthly correlation between irrigation and precipitation (Figure 7). With few exceptions, monthly peaks of precipitation correspond to peaks of surface irrigation suggesting that the system has a limited buffering capacity. This, combined with the fact that even in a "wetter" year precipitation is virtually null from June to October, indicates that water stress during the dry period is very difficult to mitigate.

In contrast, the almost identical stress results between 2001 and 2002 at the dry period could actually be an artefact of the simulation, since in both years the same Et_0 was used, and, as Table 2 suggests, Et_0 can be very variable from year to year. Outside the dry season, when precipitation and irrigation are more variable, stress strongly depends on the combination of these two factors. On March 2002 (Figure 7 a) for example, stress was very low even with relatively little irrigation (just over 20 Mm^3), because precipitation was high (about 60 Mm^3). On May 2002, the situation is reversed, and stress is zero with high irrigation and low precipitation. When comparing dry and wet years, 2002 shows five months of zero or almost zero stress, while 2001, only two (Figure 7 a and b respectively). The year 2002 resulted in an overall annual stress of 369.36 Mm^3, whereas 2001, 452.29 Mm^3.

The overall resulting loss in irrigation water due to reduced efficiency of the irrigation technology was estimated in approximately 40% of the total surface water delivered. According to the simulations, it is unlikely that this could make any difference during the dry season, but efficiency reduction could be very important during less extreme months.

4. Concluding remarks

4.1 Conclusions

There are a large number of water balance models created to answer specific questions. In this project, the idea was to create a simplified water balance model to help to understand the causes of water stress. From the scientific point of view this is a demanding approach as it requires simplifying the complex natural water system without producing oversimplifications that result in major inaccuracies. At the same time it is difficult to apply such a tool at a regional level because it requires adapting and adding model components to represent local characteristics. This means that the idea of applying such a water balance model in the test site to some extent contradicts the research objective to develop a generic tool.

The WBM is intended to represent a useful tool to stimulate discussions on water management and allocation among stakeholders, as well as to show the gaps in knowledge that are currently impairing a real integration of water management over all sectors. Due to its simplified and generic nature the model cannot represent the local conditions completely, and it may not be adequate to answer specific questions.

The calculation of the water demand in the sectors includes a combination of rules and incorporates expert knowledge. In the domestic sector some social criteria are included. Although it is possible to include additional rules in the WBM, this is not intended because a more detailed examination of the water demand calculation is better conducted by more sophisticated tools, which are already available for all sectors. The calculation of the industrial water demand was intended to takes into account the state of the art in different industrial branches and refers to the European experiences. Unfortunately the project partners were not able to provide the data. In this sector it is necessary to improve the WBM. The calculation of the agricultural water demand is always accompanied by uncertainty because much more information is often needed and some of the most influencing factors are difficult to estimate. The WBM considers the most relevant factors and became rather detailed for the agricultural sector compared to other sectors. However, it is suggested that the results be discussed with the stakeholders or local experts. The (semi-)natural sector still has many uncertainties in the way water stress is calculated, and generally suffers from a lack of data on groundwater flows and edge effects.

The Aquasstress project tends to be a stakeholder driven project. This means that the stakeholders' needs in the test sites are as important as scientific research needs.

During the project it became obvious that a stakeholder driven projects requires integrating the stakeholder early in the process, although sometimes this might lead to an overload of the stakeholder's tasks. For the development of the WBM the stakeholder should have been integrated during the writing of the proposal, that is, even before starting the project itself. This seems to be necessary because the research activies of water balance model have been defined only from a scientific point of view. From this point of view the WBM is designed as a generic tool which could be adapted to different test sites easily by small changes. While presenting the first draft of the water balance model in the test sites it became obvious that the stakeholders' interests differed from test site to test site resulting in different requirements on the structure, content and interface of the water balance model. As a result the research activities were divided into: development of generic rules for the calculation of sectorial water demand; and development of different WBM versions representing stakeholders' requirements based on the individual test site characteristics.

In the Aquastress project the stakeholder process started comparatively late due to the objective of the project to have the same working steps in all test sites. Faster developing test sites were asked to slow down to accomodate to slower developing test sites and divergent research activities were partly harmonised. This was particularly inconvenient for the work in WB 2. The result was that some test sites did not need the water balance model because they had already finished the first step of characterising the water stress. Yet other sites had to speed up the discussion in order to catch up with the sites that had already finished. In any case, at this point, the water balance model and the framework of the water stress index, which were supposed to be used as tools for stress characterization, were being established but not finished and thus could not been used. It would have been better to allow to run the stakeholder process indivually in the test sites. In this case it would have been possible to test the WBM at least in slower test sites.

If the stakeholders evaluate the WBM as generally helpful for a decision making process, it is necessary to consider also their criticism and to improve those sub systems that are found not to be appropriate. As the WBM is built up hierarchically and could be changed while discussing the water balance of a test site with stakeholders, we assume that this model could have been developed in a participatory way as well. In order to follow this idea it would have been necessary to

- identify the stakeholder of a water-related decision making process
- create mental maps of the problem of simplified water stress together with stakeholder using boxes and arrows
- elicit stakeholder knowledge on water balance components by interviews or reports
- transfer the mental maps into water balance model components
- include the knowledge about single water balance components of stakeholder in the model
- run a first calculation and discuss results with stakeholders
- adjust values and revise it.

The application of the water balance model at two test sites ended in two versions of the water balance model. They differ in the model structure and in the calculation of the water stress of single sectors. This is due to different data in the test sites and different characteristics of the test sites, e.g. not all sectors are relevant in all test sites.

Thus the USF decided to continue to work on the water balance model and to simplify it to be able to apply it as a generic tool. This approach is considered to be necessary to fulfil the research objective although continuative simplification of an already simplified water balance model cuts down the informative value and the validity of the model. In the following a short abstract of the working results is given. Further details are provided in Bahlmann (Bahlmann, 2008).

4.2 Prospect: Simplified water balance model

The simplified water balance model uses surface and groundwater inflow as input water flows of a test site. Upstream users are considered. Both types of water resources are supplied to domestic, agricultural and industrial sector by defining

- the portion of portion of surface water to agriculture
- portion of surface water to domestic sector
- portion of surface water to industry.

The semi-natural ecosystem sector is not considered due to methodological constraints. The water resources are calculated at the beginning and the end of a defined period and thus the differences in the water resources of both time steps give a first idea about potential ecological impacts in the test site but effects on the semi-natural ecosystems could not be justified.

The following figure shows the main interface of the model. Arrows indicate water flows (groundwater and surface water) whereas symbols represent places where water resources are used, transferred or changed. Pink areas with a spigot indicate water stress either due to missing surface water and groundwater. For the industrial sector water stress is indicated for both the energy branch and for the other branches as the water demand and the pattern of water use of the energy branch differs.

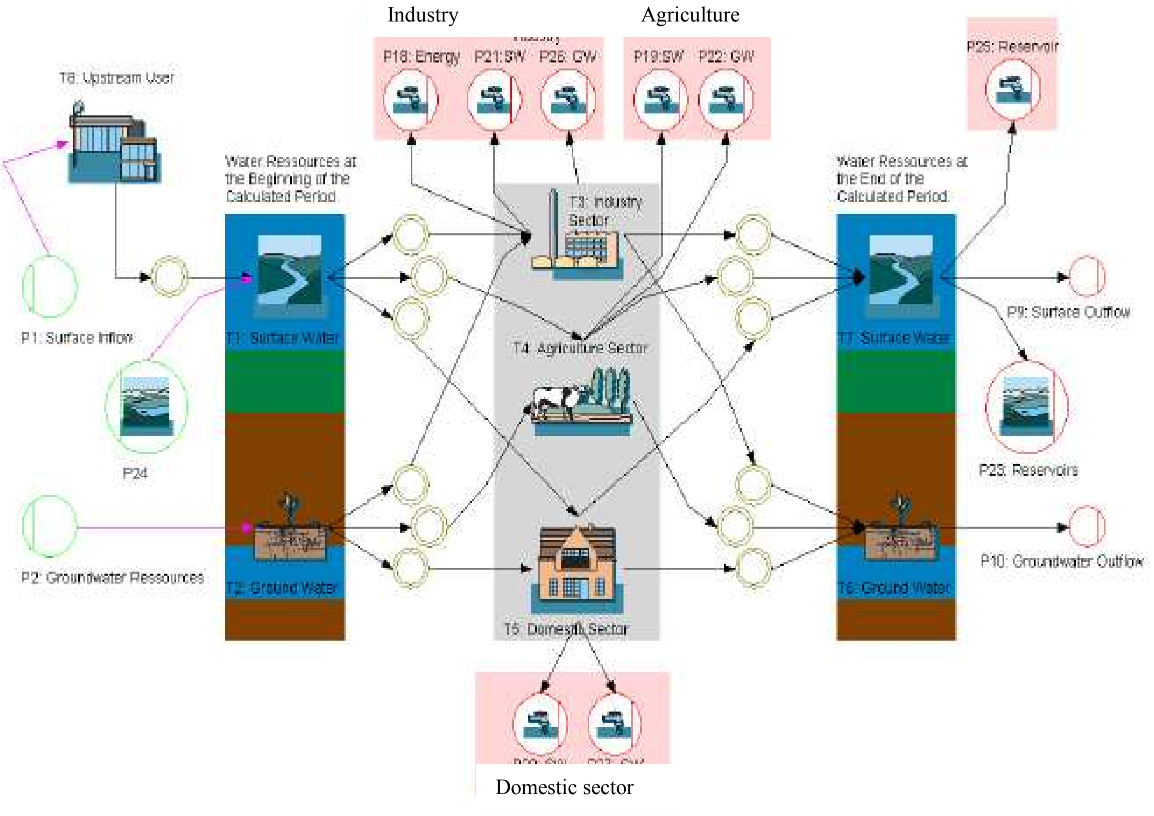
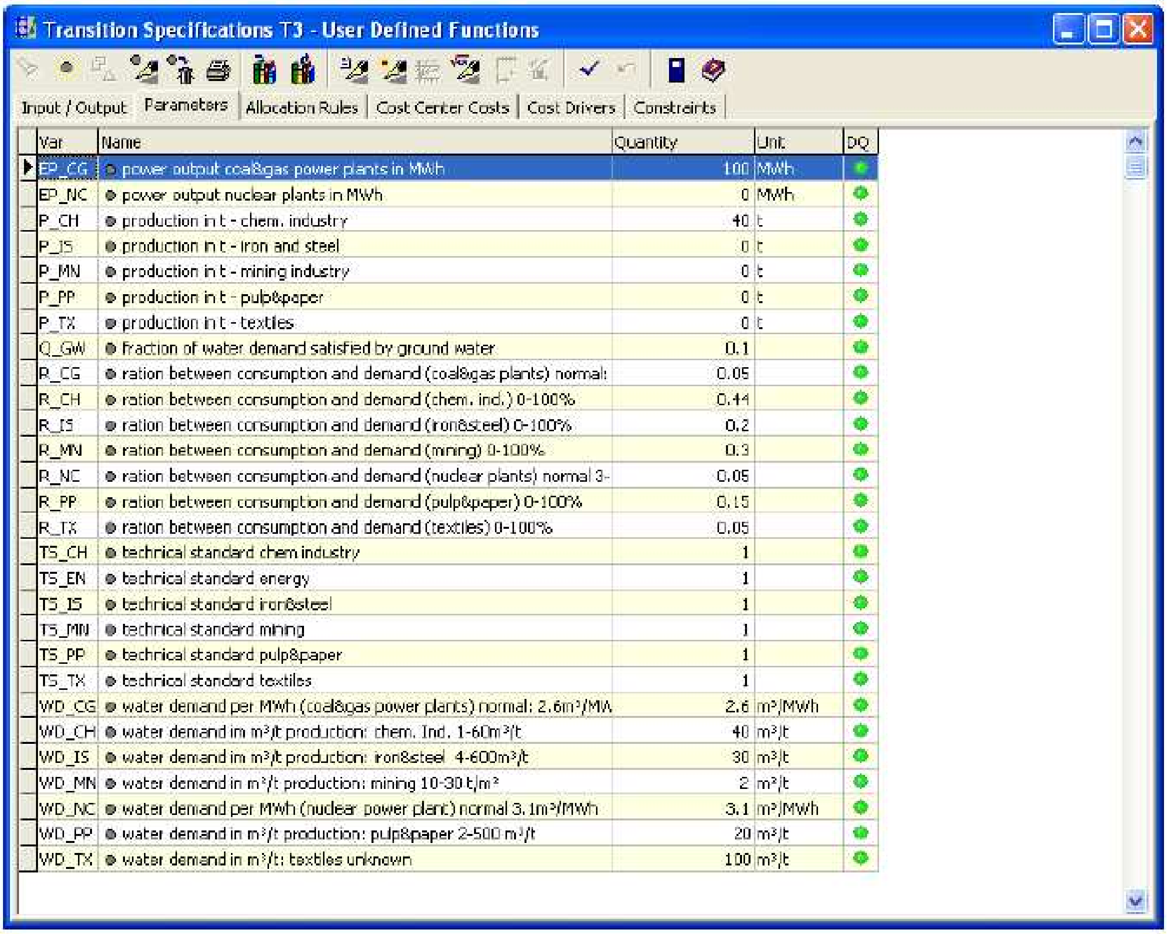


Figure 8: Interface of the simplified water balance model

The calculation of the water demand of all sectors forms the main component of the model whereas the allocation of the water resources is defined by simple distribution factors.

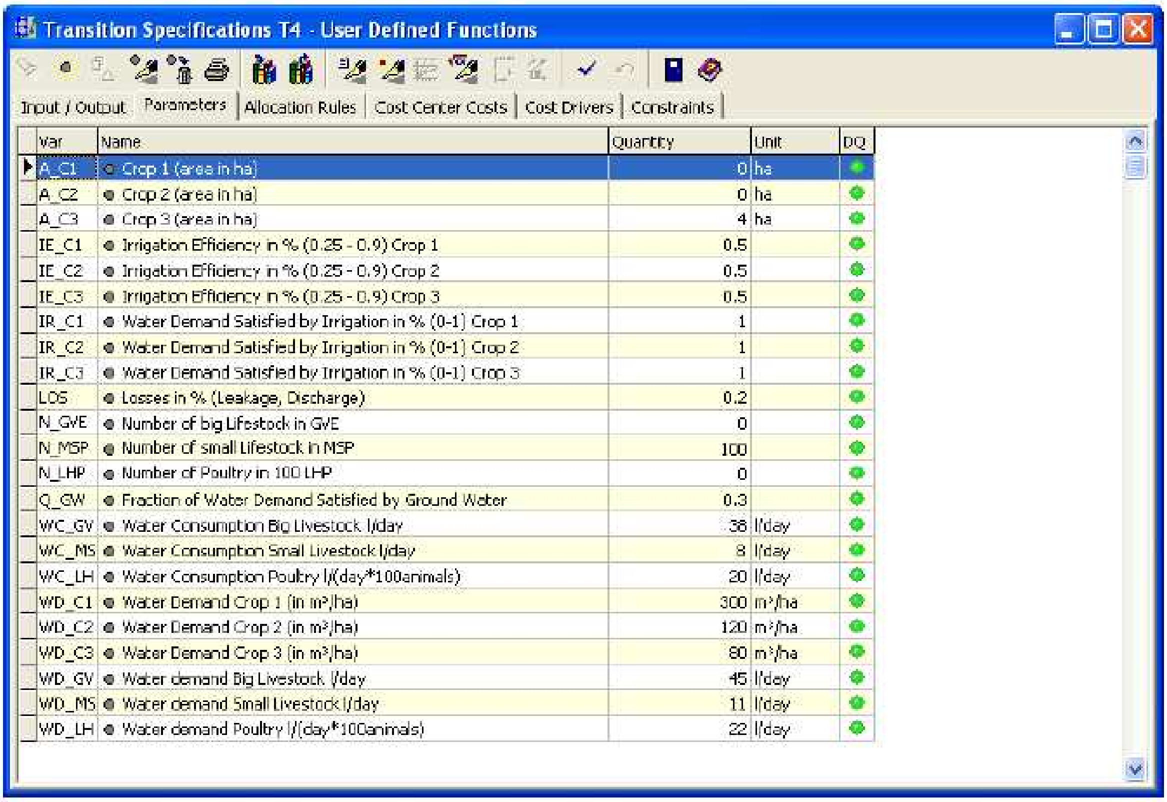
For the industrial sector the water demand of a test site is calculated on data about power output of energy plants as well as output figures of the chemical branch, iron and steals branch, mining industry, pulp and paper branch and textile branch, called EP and P in figure 9. To estimate consumed water in each branch ratio between consumtion and demands are used based on statistical averages in Germany (compare factors R in figure 9). Depending on the technical standard of each branch the water demand increases or falls. It is multiplied with the water demand of each branch, given as WD-operands in figure 9. To express water stress in the industrial sector first the water stress of the energy branch is examined. Water used for energy production is potentially available for other branches as well and thus it is not lost but changed (in quality and temperature) and supplied to the other branches. Water stress occurs if the supplied water to the energy branch is less than the calculated water demand of the branch. Water stress of the other branchs occurs if the supplied water resources to these branchs are less than the calculated water demands of these branchs.



Var	Name	Quantity	Unit	DQ
EP_CG	power output coal&gas power plants in MWh	100	MWh	
EP_NC	power output nuclear plants in MWh	0	MWh	
P_CH	production in t - chem. industry	40	t	
P_IS	production in t - iron and steel	0	t	
P_MN	production in t - mining industry	0	t	
P_PP	production in t - pulp&paper	0	t	
P_TX	production in t - textiles	0	t	
Q_GW	fraction of water demand satisfied by ground water	0.1		
R_CG	ration between consumption and demand (coal&gas plants) normal:	0.05		
R_CH	ration between consumption and demand (chem. ind.) 0-100%	0.44		
R_IS	ration between consumption and demand (iron&steel) 0-100%	0.2		
R_MN	ration between consumption and demand (mining) 0-100%	0.3		
R_NC	ration between consumption and demand (nuclear plants) normal 3-	0.05		
R_PP	ration between consumption and demand (pulp&paper) 0-100%	0.15		
R_TX	ration between consumption and demand (textiles) 0-100%	0.05		
TS_CH	technical standard chem industry	1		
TS_EN	technical standard energy	1		
TS_IS	technical standard iron&steel	1		
TS_MN	technical standard mining	1		
TS_PP	technical standard pulp&paper	1		
TS_TX	technical standard textiles	1		
WD_CG	water demand per MWh (coal&gas power plants) normal: 2.6m³/MW	2.6	m³/MWh	
WD_CH	water demand im m³/t production: chem. Ind. 1-60m³/t	40	m³/t	
WD_IS	water demand im m³/t production: iron&steel 4-600m³/t	30	m³/t	
WD_MN	water demand in m³/t production: mining 10-30 t/m³	2	m³/t	
WD_NC	water demand per MWh (nuclear power plant) normal 3.1m³/MWh	3.1	m³/MWh	
WD_PP	water demand in m³/t production: pulp&paper 2-500 m³/t	20	m³/t	
WD_TX	water demand in m³/t: textiles unknown	100	m³/t	

Figure 9: Water demand calculation of the industrial sector

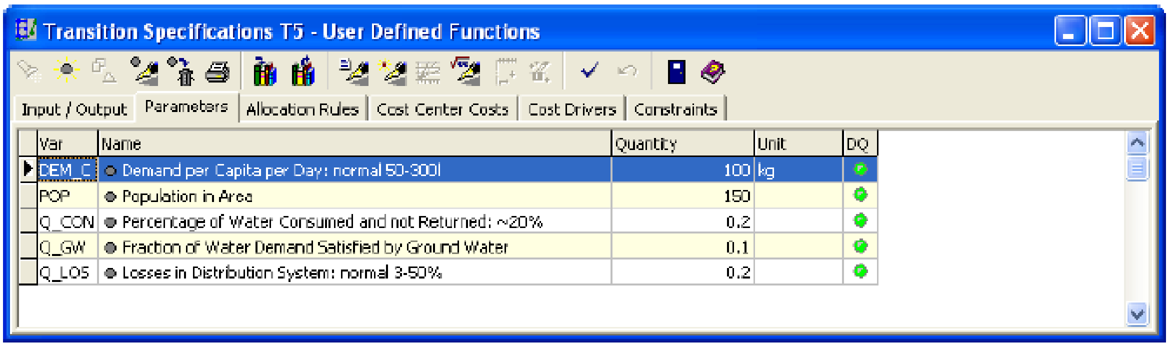
For the agricultural sector the water demand is calculate for livestock and different crop types (compare figure 10). The number of crop types could be added as much as needed. Each crop type in a test sites is considered by the surface area as well as water demand, irrigation efficiency and the water demand satisfied by irrigation. Leakages in the irrigation and supply network are taken into account. For the calculation of the water demand of livestock the number and the water consumption for big and small livestock and poultry are calculated. Water stress is expressed for the agricultural sector if the supplied water resources are less than the calculated water demands for livestock and crops in the test site.



Var	Name	Quantity	Unit	DQ
A_C1	Crop 1 (area in ha)	0	ha	
A_C2	Crop 2 (area in ha)	0	ha	
A_C3	Crop 3 (area in ha)	4	ha	
IE_C1	Irrigation Efficiency in % (0.25 - 0.9) Crop 1	0.5		
IE_C2	Irrigation Efficiency in % (0.25 - 0.9) Crop 2	0.5		
IE_C3	Irrigation Efficiency in % (0.25 - 0.9) Crop 3	0.5		
IR_C1	Water Demand Satisfied by Irrigation in % (0-1) Crop 1	1		
IR_C2	Water Demand Satisfied by Irrigation in % (0-1) Crop 2	1		
IR_C3	Water Demand Satisfied by Irrigation in % (0-1) Crop 3	1		
LOS	Losses in % (Leakage, Discharge)	0.2		
N_GVE	Number of big Lifestock in GVE	0		
N_MSP	Number of small Lifestock in MSP	100		
N_LHP	Number of Poultry in 100 LHP	0		
Q_GW	Fraction of Water Demand Satisfied by Ground Water	0.3		
WC_GV	Water Consumption Big Livestock l/day	38	l/day	
WC_MS	Water Consumption Small Livestock l/day	8	l/day	
WC_LH	Water Consumption Poultry l/(day*100animals)	20	l/day	
WD_C1	Water Demand Crop 1 (in m³/ha)	300	m³/ha	
WD_C2	Water Demand Crop 2 (in m³/ha)	120	m³/ha	
WD_C3	Water Demand Crop 3 (in m³/ha)	80	m³/ha	
WD_GV	Water demand Big Livestock l/day	45	l/day	
WD_MS	Water demand Small Livestock l/day	11	l/day	
WD_LH	Water demand Poultry l/(day*100animals)	22	l/day	

Figure 10: Water demand calculation of the agricultural sector

The water demand of the domestic sector is calculated on water demand per capita and day, population in the test site and losses in the distribution network (compare figure 11).



Var	Name	Quantity	Unit	DQ
DEM_C	Demand per Capita per Day: normal 50-300l	100	kg	
POP	Population in Area	150		
Q_CON	Percentage of Water Consumed and not Returned: ~20%	0.2		
Q_GW	Fraction of Water Demand Satisfied by Ground Water	0.1		
Q_LOS	Losses in Distribution System: normal 3-50%	0.2		

Figure 11: Water demand calculation of the domestic sector

For all operands statistical average values of the European or nation level are entered to run the model. The user of the model may change all values in order to adapt it to test site characteristics. The results of the calculation are not given as numbers but as sankey diagramm (compare figure 12) because the model should help to stir a discussion on causes of water stress without being lost in the debate about calculation details. Blue arrows indicate the flow of water resources whereas red arrows indicate water stress. The larger an arrow the higher water stress or the more water resources are flowing. The user of the model is able to compare water stress results with all other water flows within a calculation period as well as between different model runs. The model runs could either be based on different values in the calculation due to different mitigation options or due to perspectives of different stakeholders.

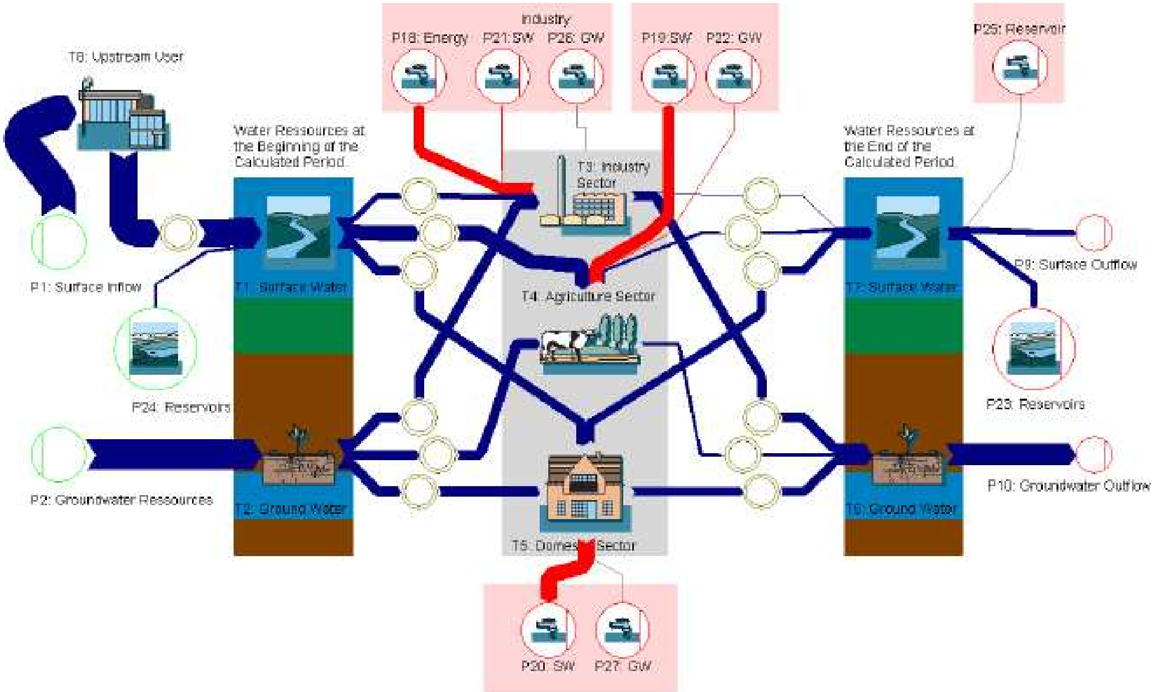


Figure 12: Flow of water resources and water stress for a calculation period

Workblock 2 of the Aquastress Project stopped working after project month 36 (January 2008). As the water balance model forms part of Workblock 2 the following working steps could not be finished: applying the simplified water balance model in one of the test sites as well as discussing the use of such a model with stakeholder in a test site.

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