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## **Integrated water balance models for water stress. Aquastress D2.3.1 - Final Report**

S. Schmidt, D. Inman, E. Preziosi, Sébastien Loubier, K. Tarnacki, M. Manez,  
I. van den Wyngaert, P. Koundouri, E. Moors, A. Olsthoorn

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# AQUASTRESS

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

Integrated Project

2.3.1

**DELIVERABLE:**

***INTEGRATED WATER BALANCE MODELS FOR WATER STRESS***

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Author(s): Sonja Schmidt, David Inman, Elisabetta Preziosi,  
Sebastien Loubier, Katharina Tarnacki, María Máñez,  
Isabel van den Wyngaert Phoebe Koundouri, Eddy  
Moors Ad Olsthoorn  
Contact for queries:  
Sonja Schmidt  
E: [sschmidt@usf.uni-osnabrueck.de](mailto:sschmidt@usf.uni-osnabrueck.de)  
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<b>AQUASTRESS</b> .....	<b>1</b>
<b>1. Introduction</b> .....	<b>3</b>
1.1 <b>Objective of the report</b> .....	<b>3</b>
1.2 <b>Working procedure</b> .....	<b>3</b>
<b>2. Water balance model</b> .....	<b>5</b>
2.1 <b>Objective of the water balance model</b> .....	<b>5</b>
2.2 <b>Characterization of the water balance model</b> .....	<b>5</b>
2.2.1 <b>Summary of milestone 2.3-1</b> .....	<b>5</b>
2.2.2 <b>Water balance approach</b> .....	<b>6</b>
2.2.3 <b>Sub systems of the WBM</b> .....	<b>7</b>
2.3 <b>Representation of WBM</b> .....	<b>9</b>
<b>3. Assessment of water stress</b> .....	<b>10</b>
3.1 <b>Definitions</b> .....	<b>10</b>
3.2 <b>Water resources assessment</b> .....	<b>11</b>
3.3 <b>Principle of assessing water stress</b> .....	<b>13</b>
3.4 <b>Water stress in a test site</b> .....	<b>13</b>
<b>4. Industrial sector</b> .....	<b>17</b>
4.1 <b>Industrial branches in general</b> .....	<b>17</b>
4.1.1 <b>Water cycle of industrial branches</b> .....	<b>17</b>
4.1.2 <b>Industrial water demand</b> .....	<b>18</b>
4.1.3 <b>Industrial water stress</b> .....	<b>20</b>
4.1.4 <b>Industrial waste water</b> .....	<b>21</b>
4.2 <b>Tourist branch</b> .....	<b>22</b>
4.2.1 <b>Tourist water demand</b> .....	<b>22</b>
4.2.2 <b>Tourist water stress</b> .....	<b>23</b>
4.2.3 <b>Tourist waste water</b> .....	<b>23</b>
<b>5. Domestic sector</b> .....	<b>24</b>
5.1 <b>Water cycle in the domestic sector</b> .....	<b>24</b>
5.2 <b>Domestic water demand</b> .....	<b>25</b>
5.3 <b>Domestic water stress</b> .....	<b>27</b>
5.4 <b>Domestic waste water</b> .....	<b>27</b>
<b>6. Agricultural sector</b> .....	<b>29</b>
6.1 <b>Water cycle of the agricultural sector</b> .....	<b>29</b>
6.2 <b>Agricultural water demand</b> .....	<b>31</b>
6.2.1 <b>Water demand of livestock</b> .....	<b>31</b>
6.2.2 <b>Irrigation water demand</b> .....	<b>31</b>
6.3 <b>Agricultural water stress</b> .....	<b>35</b>
<b>7. (Semi-)natural ecosystems</b> .....	<b>36</b>
7.1 <b>Water cycle in (semi-) natural ecosystems</b> .....	<b>36</b>
7.2 <b>Water demand of (semi-) natural ecosystems</b> .....	<b>36</b>
7.3 <b>Waste water in the environment</b> .....	<b>37</b>
7.4 <b>Water stress of (semi-)natural ecosystems</b> .....	<b>37</b>
<b>8. Concluding remarks</b> .....	<b>39</b>
<b>9. References</b> .....	<b>41</b>

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	2

## 1. Introduction

### 1.1 Objective of the report

This paper is based on the report Milestone 2.3\_1 of the Aquastress project, which presented an inventory of examples of water balance models and gave a list of criteria to characterise hydrological models. The objective of this deliverable is:

- to describe the concept of the Water Balance Model (WBM) of Work block 2 (WB 2) of the Aquastress project and
- to describe how the so-called “simplified” water stress assessment is carried out in all the sectors (industrial, agricultural, domestic, tourist and environmental sector) at a test site and in neighbouring areas. In what follows, the environmental sector will be referred to as (semi-)natural sector.

In the WBM the water stress definition of WB 2 has been used (compare with chapter 3). The assessment of water stress by the WBM is simplified compared to the water stress matrix of WB 2 because it does not incorporate all aspects of water stress which are listed in the definition of WB 2. Thus the WBM does the “simplified water stress assessment” based on water fluxes and water quality, whereas the water stress matrix takes also into account the adaptability of the test site to cope with water stress (compare with chapter 3).

Water balances and/or water balance models can be established for different spatial scales (Molden, 1997). In general, the objective of the water balance model changes according to the spatial scale. It is important to be aware of the advantages and disadvantages of dealing with water stress situations at different spatial scales: the higher the spatial scale, the broader the examination and the larger the number of issues involved, but also, the less detailed in time and space. On a regional (or broad or macro) level a basin or a sub-basin is covered and several uses of water are examined. On a local (or meso or middle) level the water balances deal with service levels such as irrigation or municipal water services. On a site specific (or micro or small) level, the water balance examines for example an agricultural field, a single household or a natural habitat related to a specific water resource.

The WBM of Aquastress provides a useful framework to characterise simplified water stress on a regional level. Molden (1997) states that in spite of the limitations of dealing with a regional level, particularly in terms of data availability and uncertainty in systems representation, experience has shown that even a gross estimate of water balances for use in water accounting can be quite useful to managers, farmers, and researchers. In the WBM simplified water stress is assessed in so called “sectors”. The industrial (including tourist), 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.

### 1.2 Working procedure

The WBM is being developed in close cooperation with projects partners in WB 2. The software which is used to run the WBM as well as the first ideas on the concept was presented during a meeting of WB 4 in Delft in February 2006.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	3

The (semi-)natural sector was discussed with partners from ALTERRA during a meeting in Wageningen in February 2006. In March 2006 the integration of hydrological data was worked out with the partners of the IRSA in Rome. Since December 2005, an exchanges as well as discussions during WB 2 and project meetings were used to elaborate the concept of the agricultural and the domestic sector in cooperation with partners from Cemagref and the University of Cranfield. The concept around the industrial sector was elaborated in cooperation with partners of the University of Aachen during a meeting in Dortmund in May 2006. During the meeting of the joint working team for the case study of Morocco first contacts to one of the test sites teams were established to coordinate future working steps, particularly to validate the calculations of the WBM for a test site.

Besides, the WBM was presented during WB 2 meetings to all work block partners in Osnabrück in December 2005 and in Wallingford in April 2006. This aimed at discussing and agreeing on the concept and the objective of the model and on coordinating activities within WB 2, especially with the development of the indicators for the water stress matrix.

In the future, the WBM will be applied to selected test sites. It is intended to use the WBM of WB 2 and to link it to an agent-based model of WB 3, which will be mainly applied in the Moroccan test site. The WBM will be tested together with stakeholder as well. The major challenge of the WBM will be to represent the water flows of the test site, which is on one hand simplified enough to avoid data-intensive calculations, but that on the other hand provides robust results to characterise water stress. Thus it is very important to validate the WBM in selected test sites.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	4

## 2. Water balance model

### 2.1 Objective of the water balance model

The most important objective of the WBM is to assess water stress in different sectors at test site level based on a simplified version of water stress than the water stress matrix. As part of WB 2 it aims at characterising water stress by identifying causes of water stress and interdependencies between the sub-systems (e.g. interdependencies between several water users), and to understand cause and effects. The objective of the WBM is neither to provide future scenario calculation nor to exactly predict the state and quality of water resources on the test site. The main objective of the WBM is to stimulate a discussion on causes of water stress and on cause and effect relationships. The WBM is built to support an understanding of the complex system of water resources and water users in an area under investigation for the layperson. The main challenge is to simplify reality and incorporate local expert knowledge in such a way that crucial elements remain meaningful and that characteristics are still included without forcing the user to go into hydrological details.

The simplified assessment of water stress is based on a comparison of physical units: water resources and water demand (compare chapter 3). In contrast to the water stress matrix, the assessment of simplified water stress of the WBM is restricted to water flows to and from sectors. It does not include for example, the ability of a test site to adapt to the situation or to the institutional setting. The WBM does neither aim at predicting future development nor at assessing water mitigation options although it may assist in identify potential ones.

The WBM focuses on a selection of the components of the water cycle: precipitation, groundwater, surface water and water abstraction. Water imports and diversions are considered as well. The objective of the model is not to calculate unknown components of the water cycle or to predict future development. The approach used in the WBM aims at incorporating knowledge about factors determining water demand of different sectors and at estimating the impact of water abstraction on water resources.

The linkages between different sub systems, like water demand of an irrigation perimeter and water abstraction from natural water resources are made explicit. Calculations used to describe interdependencies are mainly based on allocation rules. Network or transition parameters are used to implement allocation rules. They serve to calculate unknown inflows or outflows of single sub systems. For example, in the industrial sector the state of the art of an industrial branch is defined. Depending on the classification in one of the three categories (high, middle or low), the water demand changes. Thus changes in the input and/or output flow of sub systems affect the assessment of water stress in neighbouring elements.

### 2.2 Characterization of the water balance model

#### 2.2.1 Summary of milestone 2.3-1

The WBM is primarily designed to function at a regional scale. The definition of the spatial boundaries is based on both administrative and hydrological criteria. The former determines the extent of the management area and the availability of information, and the latter, the functional limits of the water cycle. The possibility of a mismatch between these two criteria certainly exists, but this

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	5

has to be resolved on a case by case basis, depending on the quality and availability of information, and on the main interests.

Within the general model there are subsystems that influence each other. The spatial structure that determines the relationships between subsystems is implicitly considered, since a spatially explicit approach requires georeferenced data, which might not always be available. Thus, the WBM can be described as a one-dimensional structure or “column” that represents the entire modelling area.

The WBM is based on relatively simple representation of the main water dynamics and water use processes of different sectors in order to estimate water demand characteristics of the system. A monthly basis for time resolution is consistent with the complexity of the modelled processes, the seasonality of life and water cycles, and with data availability.

Models could be classified as empirical, conceptual or theoretical according to the relationship they establish between input and output (Xu & Singh, 1998). The WBM is a combination of empirical and conceptual, which makes it less data intensive than a theoretical model and it can be more easily adapted to different test sites.

### 2.2.2 Water balance approach

Water balance approaches can be used for several goals. One of the most common uses focuses on estimating unknown parts of single water components of the water balance, which means a relatively stronger emphasis on water accounting and on understanding the functioning of a single system. Additionally, water balances can be used to examine the flows of water between several sub systems, by which the linkages and interdependencies between the water balance components become more important.

In general, the water balance approach is based on the purely physical law of the conservation of water mass for a given area within a defined period of time: water inflow equals water outflow plus storage change. Using a water balance approach to estimate one or more unknown sub systems assumes that enough elements of any significant magnitude are known, e.g. if precipitation and groundwater outflow are given, surface outflow could be calculated. Based on knowledge on the functioning of the system allocation rules might be included as well. Allocation rules describe how input and output flows are related. As an example for the simplest case, the input flow can be divided into two output flows depending on given percentages in mass. Allocation rules are derived from knowledge about the system itself and need to be examined before being implemented in a model.

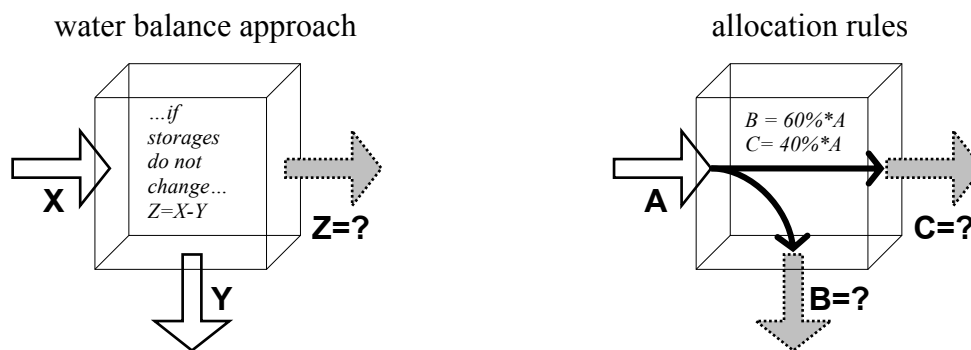


Figure 1: Approaches to calculate input and output flows of a system

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	6

Problems occur if single sub systems of the water balance are difficult to measure or even difficult to estimate. As a result, the calculations remain questionable or unsure. To provide more robust results, water balance models therefore reduce the extent of the system under investigation in time and/or space. For example, instead of calculating the changes in the surface water flow in a river for a whole month only the changes in the surface water level of a river after a rainfall of a defined intensity is calculated.

Using a water balance to make the interdependencies between subsystems explicit, it relies on the fact that, due to conservation of mass, changes in single sub systems of the water balance automatically have an impact on neighbouring sub systems in the amount and/or in the direction of flows (compare with Figure 2). This generally applies to all systems, whether they are built up of sub systems being defined by functional criteria like in the WBM, or by spatial criteria as in a grid. In most models the impacts of a selected sub system are transferred to neighbour sub systems following the flow of water. The WBM is able to represent effects in both directions, following the flow of water and against the flow of water, which is necessary to represent interdependencies.

This type of water balance model can be used, for example, to evaluate the effects of a dam on regional water resources. The building of the dam increases the storage capacity of the system. While filling the storage the outflow of the system is reduced and this might cause negative effects downstream. Additionally it modifies the natural hydrological regime in the intra-annual period and might divert water from the former outward flow. Irrigation with surface water, for example, changes the flow direction of surface water which might cause negative effects such as the rising of the groundwater table and the reduction of the surface outflow downstream. Additionally, water use by human might affect the quality of water components.

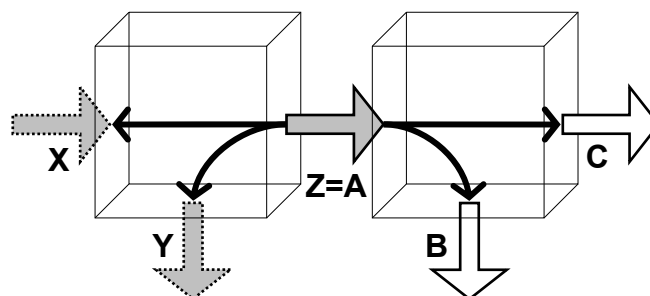


Figure 2: Effect of changes in input and output flows of a system on neighbouring sub systems

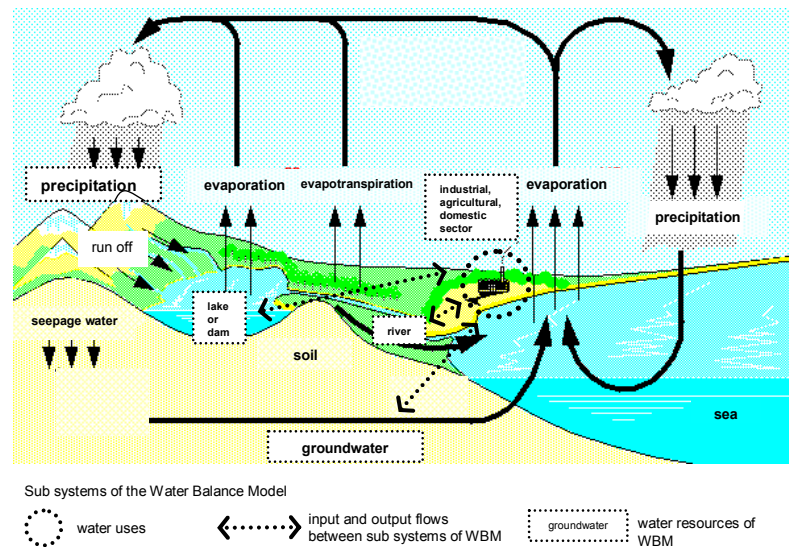
### 2.2.3 Sub systems of the WBM

The WBM focuses on a selected number of components of the water cycle. It aims neither at representing the complete water cycle nor at examining single components in detail. Figure 3 represents all components of the water cycle and uses dotted text frames to indicate which components are included in the WBM. The dotted arrows indicate which relationships between water users and water resources are examined in the WBM.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	7



The WBM performs a simplified water stress assessment in the selected sectors by comparing water supply and water demand of each sector. It links water users to water resources and includes factors affecting both the amount of available water as well as the water demand of a sector. The WBM focuses on the impact of human activities on the natural water resources. For example, it does not calculate the changes in the height of a groundwater table but it calculates storage changes in a groundwater aquifer by comparing inflow and outflow to the aquifer. The water abstractions of sectors as well as the disposal of used water or waste water of the sectors are also incorporated.



**Figure 3: Components of the natural water cycle and sub systems of the WBM**

For the test site level the WBM considers the following components:

- as inflow: precipitation, trans-basin diversions, groundwater and river inflow, diversions
- as storage change: both reservoir storage change and groundwater storage change
- as outflow: river and groundwater outflow, diversions

For single sub systems additional inflows or outflows are examined. Evaporation and evapotranspiration are not considered on the test site level because the WBM does not aim at balancing the whole water cycle. But for the agricultural sector evapotranspiration is calculated to estimate the water demand of irrigated agricultural areas. For the water supply networks water losses, both to soil and atmosphere, are estimated. Again, this is not done to do the water cycle calculation of the test site but to estimate water losses while supplying abstracted water to agriculture (compare with chapter 4ff).

Surface run-off is generally not included since the WBM is not spatially implicit but lumped. The amount of run-off is strongly depending on the type and duration of a precipitation event, on the soil characteristics, on land use and additional water inflow and the terrain slope.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	8

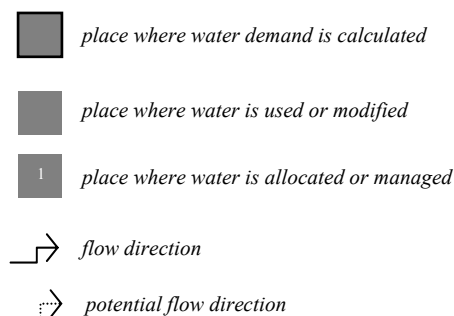
## 2.3 Representation of WBM

In the chapters 4ff the concept of the WBM is explained in detail for single sectors. Graphs show the structure of sub systems using boxes to represent places where water is used or modified and arrows to indicate the flow of water, pollutants and nutrients (Figure 4).

There are three different types of places defined. 1. Places with a number represent the so-called “set screws” which allow allocating outgoing water flows or changing the originating sources of an incoming water flow. For example, if a collective water supply network abstracts water from groundwater and surface water the proportion of each source (e.g. groundwater 40% and surface water 60%) will be included in such an allocation place. In case water managers decide to change the proportion of a source, the allocation rules could be easily changed to e.g. 50% and 50%. 2. Places where water demand is calculated are indicated with a black frame. For example in the agricultural sector at least two places are defined to calculate water demand: irrigation perimeter and livestock. 3. Places without number and without dark frame represent the modification of water, e.g. a waste water treatment plant or the water supply network.

The arrows indicate the direction of material flow between places. In the WBM water and related materials – nutrients and pollutants – follow these arrows. The WBM generally includes water quality status. For example, information obtained from the literature and reports on the emission loads per capita per day are used to calculate the quality of waste water of the domestic sector. In case waste water is not treated and directly diverted into a surface water body, water stress might occur if thresholds are not met (compare with chapter 7). As a prerequisite thresholds for open surface water body have to be defined. The available amount of water for a test site can be cited as another example. Supplied water is considered to be available for a sector only if it meets the standards of a specific water use of a sector. This means that water of poor quality is not considered to be available and thus water availability of a sector might decrease if the water quality deteriorates.

An arrow includes all the materials flowing between two places. In general the flow direction and the material flow are known. If only one of them is known the arrow is represented by a dotted line to indicate a potential flow direction.



**Figure 4:** Graphical representation of elements of the WBM

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	9

### 3. Assessment of water stress

#### 3.1 Definitions

The report is based on the definition of water stress elaborated in Work block 2 (compare with chapter 3.3) and on the following definitions mainly based on the European Environmental Agency:

- **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). This part of the definition is similar to the “natural renewable water resources” defined by World Resources Institute (2006) at the country scale, which states that: the sum of average annual flow of rivers and the recharge of groundwater (aquifers) generated from endogenous precipitation (occurring within the country’s borders), plus natural flows originating outside of the country. 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 and are defined as water losses.
- **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 irrigations 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 part of water which is reserved for other uses (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. In the case of the WBM sectors are defined as water uses.
- **Sector water supply** is the amount of water supplied to a single sector and intended to be used in that sector. This amount of water has been made available for a single sector. It is calculated by taking into account committed water as well as water losses of the water supply network. The amount of sector water supply depends on: the amount of water abstracted from the water resources, on the amount of water which is dedicated to other sectors, on upstream water users, on the losses of the supply network, and on 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 literature results, statistical data and/or on local expertise on water needs of different sectors.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	10

Figure 5 shows the relationship among the above definitions of water. The sizes of the bars do not indicate a volume or proportion. It shows for example that a portion of abstracted water is lost while being supplied to a sector.

<b>water resources</b>			
<b>water abstraction</b>		<b>non abstracted water</b>	
<b>water supply</b>		<b>water losses</b>	<b>evapo(transpi)ration</b>
<i>sector water supply (for a sector X)</i>		<i>committed water to other sectors than X</i>	
<i>water consumption of sector X</i>	<i>return water of sector X</i>		

**Figure 5: Definition of terms**

Water resources could be additionally divided into renewable and non-renewable or exploitable and non-exploitable resources. These subcategories are not used in the WBM because they require a further assessment of the water resources. The exploitability of water resources depend on the technical level of infrastructure and/or on the financial power, as well as on the type of water resource. It might be difficult to assign water resources as being currently exploited, or as currently not exploited but exploitable in the near future, or as exploitable in the future but not currently, due to a lack of infrastructure or investment.

### 3.2 Water resources assessment

In order to perform an overall evaluation of the water resources for the test sites, the scheme shown in Figure 6 has been adopted. The upper cylinder represents the surface system, the lower one the aquifer/s. Possible “inputs” and “outputs” to the site are represented by blue and red arrows respectively; exchanges between surface water and groundwater are also shown. The main aim of this evaluation is to establish how much water is actually available inside the boundaries of the site, due the water that naturally enters (as precipitation) the area, and then produces surface runoff or infiltrates to groundwater. It also accounts for the flow originating outside the site and available on the site (surface and groundwater), plus the water which is artificially imported from the neighbouring areas or produced by desalination. This scheme is used for the modelling of the (semi-)natural ecosystems.

The test sites in the Aquastress project widely differ from both climatic and water uses point of view. The different situations analysed led us to design a very general scheme for the water balance, considering all the possible types of fluxes entering and exiting the test site, which results in the scheme of Figure 6. Inputs to the surface system are endogenous precipitation (feeding flow of rivers and the recharge of groundwater), the natural discharge of rivers entering the system, ground waters feeding springs and rivers (base flow) inside the area, artificial water imports (diversions, desalination, etc.). The outputs are all fluxes exiting the system, including the water consumed in any process. Surface waters can eventually infiltrate to the aquifers, hence they could still be part of the available resources. The fraction of the precipitation entering the surface system and then recharging the aquifers is to be considered obviously only once.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	11

While considering groundwater it is important to individuate whether the aquifers are completely included inside the boundaries of the site. If not, the boundaries of the underground system are “flow boundaries” and the volumes per time unit entering and leaving the system should be estimated. Obviously this is the same difficult task than in the case of a surface system. Moreover, the eventual exploitation of the upstream part of the aquifer should be taken into account. The volume of water resources common to both surface and groundwater (overlap) should not be counted twice. That is, contribution of aquifers to surface flow, recharge of aquifers by surface run-off should be accounted for only once.

From a theoretical point of view the assessment of the water resources seems to be a simple task, just an algebraic sum of inputs and outputs. However difficulties arise in numbers inversely proportional to the size of the study area, as appropriate information seems to be more difficult to be obtained at the site scale than e.g. at the nation level. Evaluation of water resources at the country scale generally consider the natural internal endowment (usually estimated from precipitation rates or from river discharge data), plus the eventual flows coming from neighbouring areas, when not committed to other users. At the site scale (typically from tens to hundreds of square km) artificial diversions (importing or exporting water) are not negligible in relation to the primary endowment and should be assessed. While accounting for the renewable resources, time variability (at seasonal and interannual time scales) should be considered. As a general rule using annual averages to determine the available resource could be misleading, especially in river systems, as water availability naturally decreases during the dry seasons. Also, river surface runoff excess could be considered as a resource only when it is possible to store it (e.g. in natural or artificial basins) for later use. However, data on yearly averages are more often available than monthly or daily data. In the WBM monthly data are used when possible.

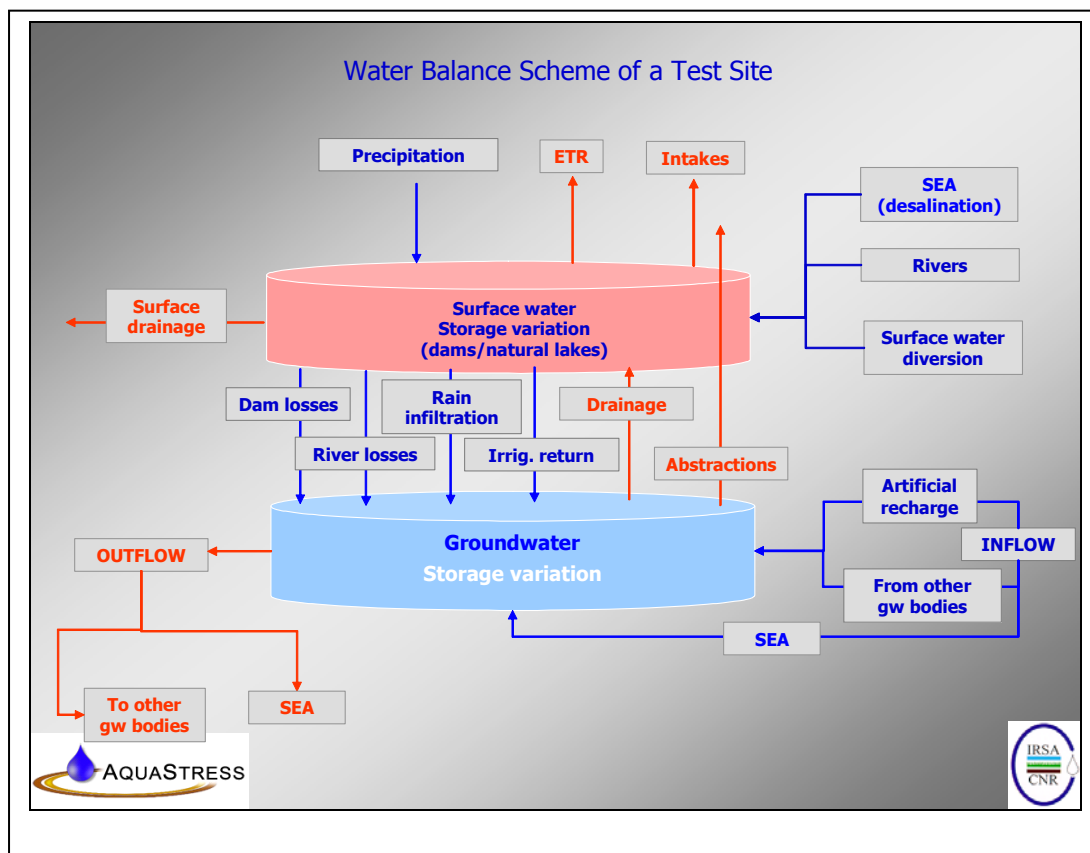


Figure 6: Water balance scheme of a test site

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	12

### 3.3 Principles of simplified water stress assessment

The WBM is used to assess water stress in a test site. The definition of water stress refers to the Aquastress report D2.1-1, which was prepared during a WB 2 meeting in 2005. The definition states that water stress occurs when the functions of water in the system do not reach the standards (of policies) and/or perceptions (of the population) on an appropriate quantity and quality, at an appropriate scale; and the adaptability for reaching those standards is not given. Under “standard” should be understood the “level” needed for the whole ecosystem (understanding humans as a part of the ecosystem). Usually these standards are described by political bodies. Since ecosystems cannot talk, the political bodies for ecosystems would be NGOs or any scientific publication.

In WB 2 of the Aquastress project two approaches are used to assess water stress for the sectors on a test site: the water stress matrix and the water balance model. The water stress matrix is built on a couple of indicators to assess water stress in several sectors (Deliverable 2.1.-2, forthcoming). Then the matrix aggregates the results of the indicators to produce a water stress index. The water stress indicators take into account the ability of a sector to adapt to a water stress situation. As a result, water stress increases if a sector on a test site shows less ability to adapt to a given situation.

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. Water stress in a sector occurs if the water demand of the sector is higher than the sector water supply (Figure 7). 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).

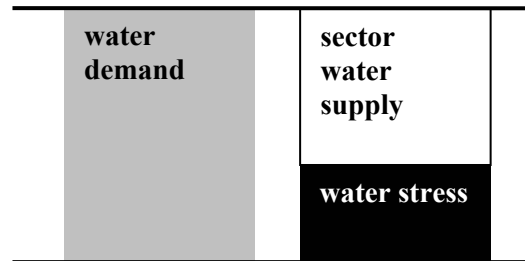
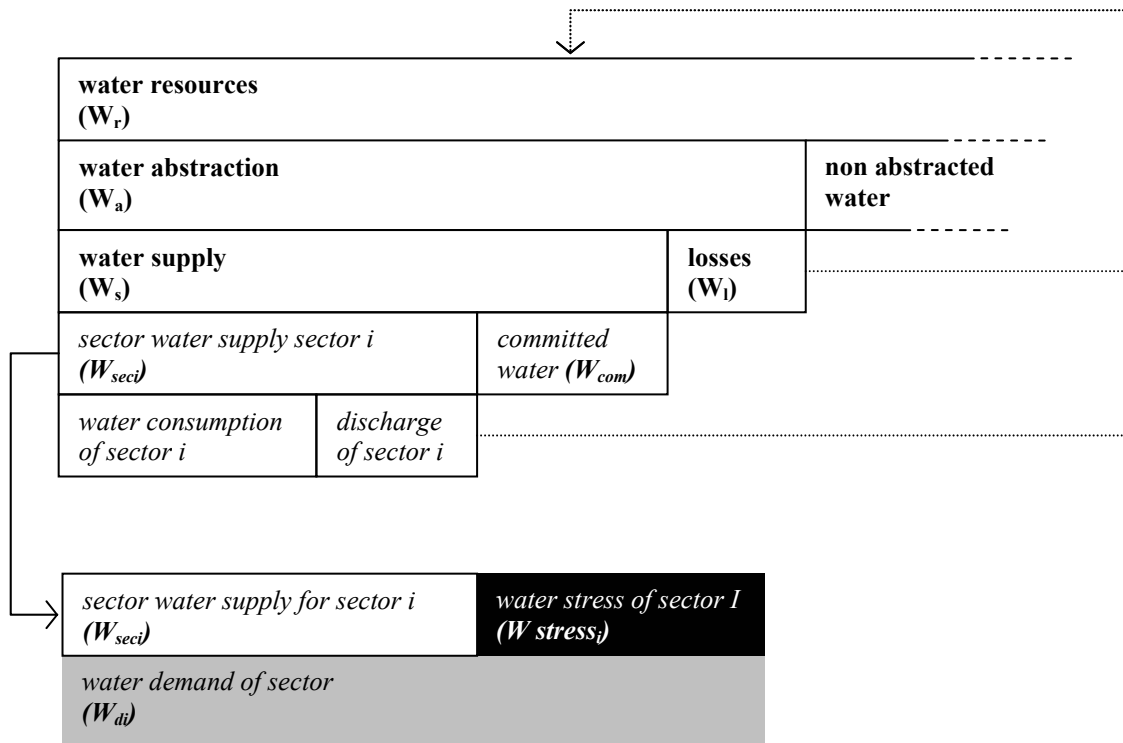


Figure 7: Simplified water stress assessment based on a comparison between water demand and sector water supply

### 3.4 Water stress in a test site

Within a test site, water stress is calculated for the following sectors: domestic, agricultural, industrial (and tourist) and (semi-) natural ecosystem. The calculation is based on monthly data. 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 8).

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	13



**Figure 8: Definition of terms and relation between water flows and simplified water stress**

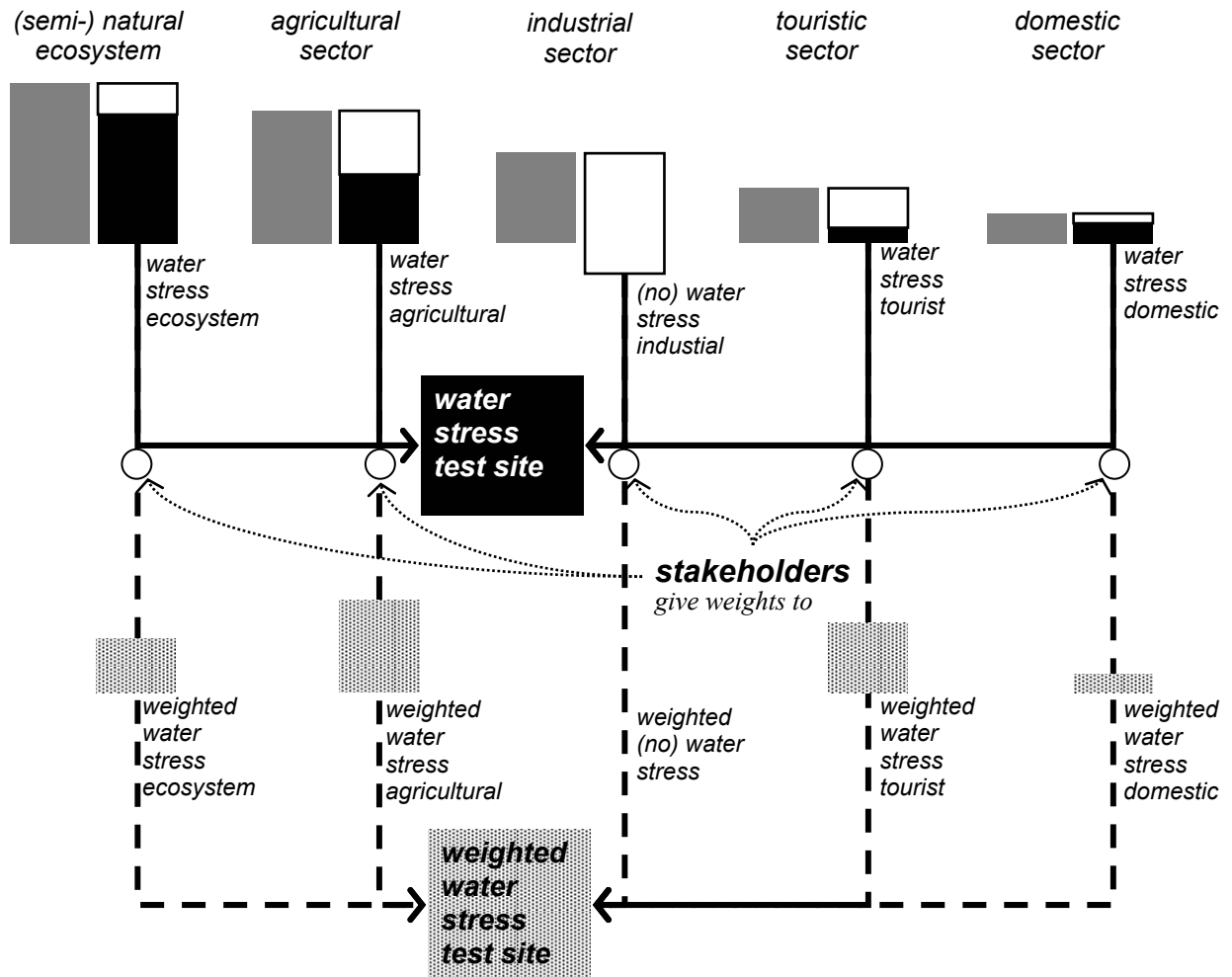
The supplied water of the domestic, industrial, tourist and agricultural sector is calculated using the amount of abstracted water and subtracting water losses and water committed to other sectors.

So, for sector i:  $W_{seci} = W_a - W_l - W_{com}$

The available water for the (semi-) natural ecosystems is calculated for each type as inflow from groundwater; surface water and precipitation (chapter7ff). It is not possible to calculate the remaining water or the non abstracted water which remains in the environment as available water because there are high uncertainties in determining all water resources in the test site, in estimating evapotranspiration for the whole test site area, and in including run-off as inflow to surface water. For all sectors the water quality is considered while calculating sector water supply. Depending on the quality requirements of specific water use the amount of available water is reduced by the portion of water which does not meet the standards.

The water demand of the domestic, agricultural, tourist and industrial sectors are induced by human activities although e.g. plants in agriculture determine the water demand for irrigation or technical requirements determine the water demand of industrial units. If the WBM is applied to selected test sites, it is necessary to adapt the calculation of water demand to the needs of the sectors in the test site. It is also possible to include stakeholders` knowledge in the calculation of single components in order to make use of the local expertise. The water demand of the (semi)-natural ecosystem is estimated based on a classification of types of ecosystems and their average monthly evapotranspiration.

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 more water stress (Figure 9). The example in Figure 9 shows the highest water stress in (semi-) natural ecosystem, followed by agricultural, domestic and tourist sector (size of black boxes in Figure 9). The industrial sector does not show any water stress. The water stress of the test site is calculated by summing up the water stress results of all sectors.



**Figure 9:** Comparison of simplified water stress assessment based on factual analysis and including stakeholders' weighting

The calculation of the water stress might include the stakeholders' perception. Deriving from the stakeholder interviews the sensitivity of each sector towards water stress is included by weighting: the more sensitive a sector against water stress, the higher the weight (compare circles in Figure 9). The calculated water stress for each sector is multiplied with the stakeholders' weight. Finally the total weighted water stress for the entire test sites is calculated as the sum water stress per sector. It is important to keep in mind that the weighting depends on the number and type of stakeholder interviews and interpretation of these interviews. Thus, transferring weighted results to other test sites is not possible.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	15



For interpretation it is possible to compare the weighted and unweighted simplified water stress results within a sector and the same test site. The comparison will reveal the difference between factual analysis and stakeholders' perception of water stress within a sector and for the whole test site. As example in Figure 9 water stress in the agricultural sector is perceived by the stakeholders as the highest in the test site although the calculation of supplied and required water flows results in the highest simplified water stress in the environmental sector. It is also possible to compare the water stress results of different sectors.

Water stress will be additionally calculated upstream and downstream of the test site. To assess water stress outside the test site, data on water abstraction downstream and upstream as well as the committed water downstream and the water demand upstream are needed. If this information is not available the inflow to and the outflow from the test site do not take into account neighbouring effects.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	16

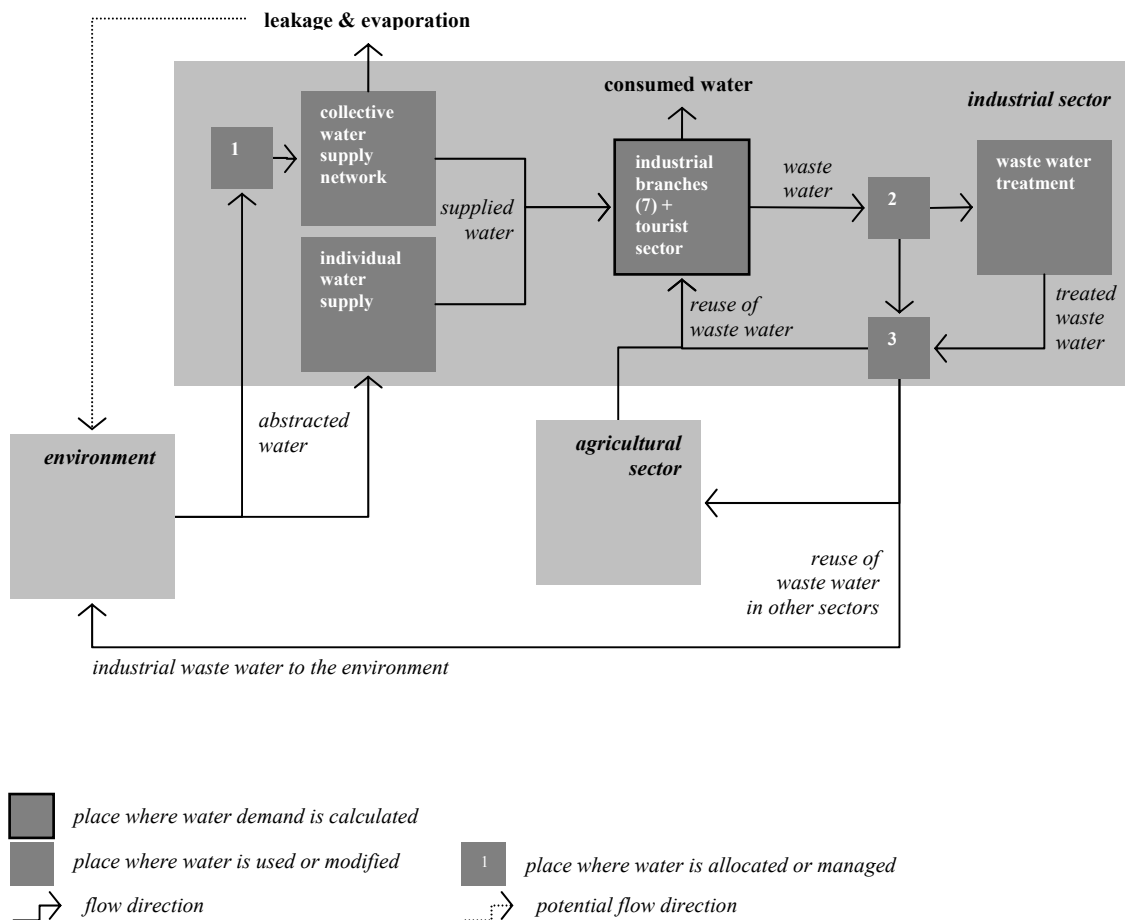
## 4. Industrial sector

### 4.1 Industrial branches in general

The industrial sector is divided into “branches”. In the model description the tourist sector is considered as part of the industrial sector, although it might share the water infrastructure with the domestic sector and its water using habits resemble more the domestic rather than the industrial sector. The tourist sector is included in the industrial sector given its economic relevance on a test site. From the conceptual point of view, however, in the WBM, the tourist sector is treated as a sector of its own.

#### 4.1.1 Water cycle of industrial branches

The industrial sector abstracts water from water resources using a central water supply network which might be shared with the domestic sector. Additionally water might be abstracted for individual industrial production units directly from surface water or groundwater in case private wells or reservoirs are operated by the industrial plant. The water demand is calculated for each of the industrial branches individually and might greatly differ.



**Figure 10: Components of the water balance model of the industrial sector**

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	17

The waste water flow is considered as well. Many industrial plants operate their own treatment plants, some only as pre-treatment before discharge to the sewerage and further treatment with municipal waste water (e.g. waste water from textile industry), and others with secondary treatment for the direct discharge to the rivers. Cooling water is often operated in closed-loop cycles with high recycling rates. Process water can also be recycled depending on the quality of the waste water and the requirements of a production unit. Additionally waste water could be reused in other sectors, e.g. water from hydro power plants could be used for irrigation.

Water stress in the industrial sector is evaluated in the following industrial branches:

1. iron and steel
2. textile
3. food and beverages
4. chemical/pharmaceutical
5. pulp and paper
6. energy
7. mining and
8. tourism.

#### 4.1.2 Industrial water demand

The industrial water demand depends on the type of industry branch, the number and type of production units, the productivity, the cooling system, the energy consumption and the technical standard of the industrial plant (EEA, 1999). For the calculation of the water demand average numbers of some European countries are used assuming a high technical standard. According to the technical standard, each branch of the test site, could be classified as high, medium or low.

In the water balance model the following information is used to calculate the industrial water demand:

- portion of industrial plants of a specific branch in the test site area to total number of industrial plants in test site area (in %)
- productivity of industrial branch (in kg or l/month)
- water demand of the industrial branch (in l/kg or l product) (water demand could be specified in l/product of different production units if possible)
- assessment of the technical standard of the industrial branch (by stakeholder or expert) in high, medium or low.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	18

**Table 1: Water demand of industrial branches**

<b>industrial water demand</b>	<b>value</b> (high standard)	<b>unit</b>	<b>source</b>
<b>pulp and paper</b>			
pulp	200 150-400	l/kg	Koppe, 2006 ATV, 1985
paper	2-20	l/kg	ATV, 1985
pulp and paper	30-500	l/kg	EEA, 1999b
<b>iron and steel</b>			
steel	50 65-130	l/kg	Koppe, 2006 ATV, 1985
iron and steel	30-600	l/kg	EEA, 1999b
<b>food and beverage production</b>			
sugar fabric	30 5-10	l/kg sugar	Koppe, 2006 ATV, 1985
tinned food	5-40 20-45	l/kg	Koppe, 2006 ATV, 1985
beverage	1-15	l/l	EEA, 1999b
<b>chemical and pharmaceutical industry</b>			
synthetic	200-500	l/kg	ATV, 1985
<b>mining industry</b>			
hard coal	20-30	l/kg	ATV, 1985
<b>textile industry</b>			
textile	40-300	l/cloth	EEA, 1999b

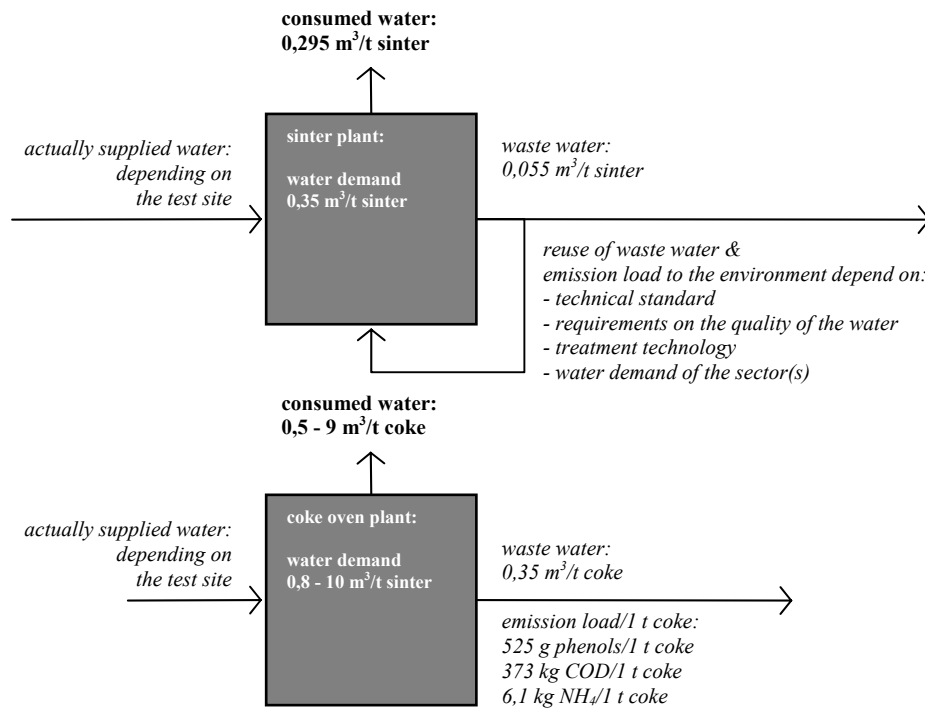
**Table 2: Water demand of small trade**

<b>industrial water demand</b>	<b>value</b> (high standard)	<b>unit</b>	<b>source</b>
<b>small trade</b>			
bakery	150	l/e*d	Koppe, 2006
confectioner	200	l/e*d	Koppe, 2006
butcher	250	l/e*d	Koppe, 2006
coiffeur	200	l/e*d	Koppe, 2006
laundry	40	l/kg cloths	Koppe, 2006
slaughter house	5000	l/animal	Koppe, 2006
market hall	30	l/m <sup>2</sup>	Koppe, 2006

*e = employee d = day*

The technical standard could be classified as high, medium and low either by stakeholder or experts. A high technical standard indicates lower water demand because resources are used more efficiently due to the use of innovative technologies. If the technical standard decreases, the water demand rises. The water demand is higher if the technical standard is low (often inefficient water use, leakages and other water losses). Based on the Best Reference Documents the values of the water demand in

Table 1 will be assumed for representing a high technical standard. According to the middle and low technical standard the values will be changed.



**Figure 11: Example of water demand and waste water of production units: sinter plant and coke oven plant (BREF on Iron and Steel, 2001)**

Depending on the best available techniques, reference document on the production of iron and steel (BREF on Iron and Steel, 2001) the amount of waste water and the water demand of single production units could be estimated. It is assumed that these values refer to a high technical standard. The amount of consumed water could be estimated. The emission load per production unit will be calculated using the amount of waste water and the average emission content as the basis. The emission load will change depending on the technical standard. The concentration of the treated waste water is affected depending on the treatment technology

Currently the emission load of industrial sectors is not included in the WBM. Furthermore there is still a discussion if and how charges could be included in the WBM because they are relevant and have an impact on the amount of water used in different branches. While applying the WBM to a test site, the integration of waste water and the type of charges will be tested for a selected branch.

### 4.1.3 Industrial water stress

In order to assess water stress the industrial water demand is compared to the supplied water to the industrial sector. Water losses in the supply network are estimated. If the volume of water requested

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	20

by the industrial sector is higher than the supplied volume of water, then water stress occurs. Water stress is mitigated by

- reducing the water losses of the water supply network
- change of the cooling system (from wet to dry, from once-through to closed loop)
- changing the portions of single industrial branches
- increasing the technical standard
- application of cascade water use
- increasing the recycling rate within the plant (closing of water cycles).

The Deliverable D 2.1.3 of the Aquastress project includes further information on industrial water stress and could be used to get a more detailed picture about the industrial sector.

In the current version of WBM it is assumed that effects of water saving technologies and water recycling both are included in the technical standard. In case it is possible this assumption could be refined. If water is reused outside the industrial sector, this will be taken into account while evaluating the other sectors because they receive an additional input flow.

#### 4.1.4 Industrial waste water

The waste water of the industrial sector is calculated based on the connection rate to a treatment plant, the emission loads of treated and untreated waste water. The emission load of each industrial branch is based on the BREF documents.

If values are not available, the emission load of treated waste water is estimated based on treatment thresholds.

Problems which might occur while applying this approach in a test site:

- does the calculation of the water demand meet the characteristics of the test site? Is the water demand estimated “correctly” and how could this be evaluated?
- how much water is actually supplied to the industrial sector and to each industrial branch?
- from which water resource is water abstracted for the industrial sector?
- to whom is water delivered in priority? To the industrial sector or to others?

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	21

## 4.2 Tourist branch

The tourist branch abstracts water from the available water resources and uses the collective water supply system, which is mostly shared with the domestic sector. If a sewage system exists it always takes up the waste water of both the domestic sector and the tourist branch. Additionally water might be abstracted for single tourist facilities. The water demand is calculated for different types of tourism. Waste water might be treated or untreated. Reusing waste water is not taken into account but water saving technologies might be in use. Depending on the technical standard and the awareness of water stress problems, different options are considered.

The calculation of the tourist water demand is difficult, especially for the tourist infrastructure because there is a huge variety of different standards. Furthermore it is difficult to estimate the volume of water supplied to the tourist sector as the same network is used for the domestic and partly the industrial sector as well. In some areas already water saving technologies are in use but it is difficult to estimate the reduction potential of these mitigation options.

### 4.2.1 Tourist water demand

The tourist water demand is calculated for tourist infrastructure and for the tourists themselves. The water demand of tourist infrastructure depends on the percentage of tourist facilities with swimming pool and the surface area of irrigated tourist green area. The water demand of the tourists depends on the type of tourism (hotel, camping etc), the number of overnight stays and the duration of tourist season.

The tourist water demand is calculated based on the following operands:

- number of overnight stays in the tourist season per day
- duration of the tourist period in days (indicating the months)
- water demand of different types of overnight stays (including tourist infrastructure at the place itself, e.g. swimming pool at the hotel...) in l/type of overnight stay
- water demand of tourist infrastructure depending on garden area:  
 water demand of golf courses in l/m<sup>2</sup> and period  
 water demand of parks in ...

**Table 3: Example of water demand of tourist sector**

tourist water demand	value	unit	source
garden area, irrigated	0,1	l/m <sup>2</sup> *d	Koppe, 2006
hotel, high standard (e:g > 1)	600	l/(g+e)*d	Koppe, 2006
hotel, middle standard (e:g = 0,5)	375	l/(g+e)*d	Koppe, 2006
hotel, low standard (e:g = 0,25)	150	l/(g+e)*d	Koppe, 2006
swimming pool	200	l/g	Koppe, 2006
restaurants	50	l/(g+e)*d	Koppe, 2006
accommodation	200	l/overnight stay	Haberl, 2006
guest house/tavern	15	l/g*d	Haberl, 2006

*e = employee, g = guest*

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	22

## 4.2.2 Tourist water stress

In order to assess simplified water stress the tourist water demand is compared to the supplied water to the tourist sector. Water losses are taken into account. If the volume of water requested by the tourist sector is higher than the supplied volume of water, then water stress occurs in the sector. Water stress is mitigated by reusing waste water or by using water saving technologies, by changing the tourist infrastructure or the type of tourism.

## 4.2.3 Tourist waste water

The waste water of the tourist sector is calculated according to the domestic sector. Depending on the number of overnight stays the emission load per capita and day is assumed (compare chapter 5ff).

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	23

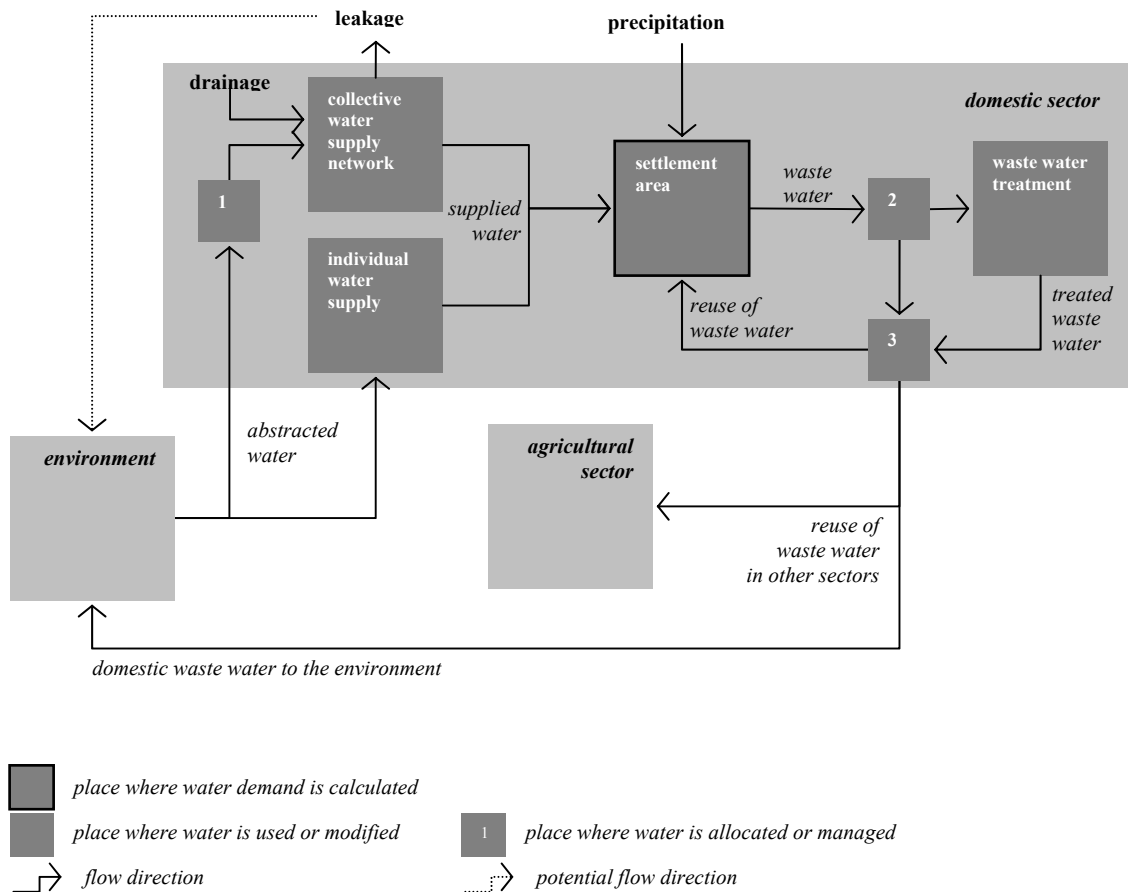


## 5. Domestic sector

### 5.1 Water cycle in the domestic sector

The domestic water cycle contains a collective and an individual water supply network. Both abstract water from natural water resources. In case the abstracted water does not meet the standards of drinking water a pre-treatment might be necessary. If the water resources do not meet the standards of drinking water, then water cannot be used from that specific source which might reduce the abstraction of water for domestic water use.

Depending on the age, maintenance and standard of the infrastructure there are water losses and additional water inflow within the supply network. Both are calculated in the WBM and linked to the collective water supply network as leakage and drainage. Supply interruptions reduce the amount of actually supplied water for households being connected to a collective supply network. In the WBM supply interruptions are included as percentage of time without connection compared to total time period of a month. Either a measured value or a rough estimation could be included.



**Figure 12: Components of the domestic sector: input and output water flows of the domestic sector, allocation of water and places**

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	24

Water demand and waste water is calculated for a settlement area. It is possible to define several settlement areas if necessary. The waste water flow to the environment depends on the percentage of household being connected to a sewage system, the percentage of the sewage system being connected to a waste water treatment plant and on the type of waste water treatment plant. The WBM assumes that if the technical standard is high, grey water is reused in the domestic sector and replaces water for toilettes. Rainwater harvesting is taken into consideration as well. Both options do not affect the calculation of the water demand but they change the flow of water in the sub system and are added to the amount of water from the supply network to the households.

## 5.2 Domestic water demand

The calculation of the domestic water demand is based on the calculation of the volume of water per capita and day related to different water uses (compare Table 4). It is assumed that these amounts of water are requested to fulfil the specific needs per person per day. The water demand is then extrapolated to a monthly volume for a defined settlement area taking into account the number of inhabitants of this area and the percentage of persons requesting these water uses.

It is assumed that a minimum water demand of 25 l per capita per day is necessary to ensure cooking and personal hygiene (Kürschner-Pelkmann, 2003). The water demand increases depending on the following water uses for:

- dish wash
- washing machine
- toilette/bidet
- shower/bath
- car washing and
- irrigation of market garden.

**Table 4: Example of water demand of domestic sector**

domestic water demand	value	unit	source
shower/bath	40	l/cap*day	Kürschner-Pelkmann, 2003
toilette/bidet	42	l/cap*day	Kürschner-Pelkmann, 2003
washing machine	18	l/cap*day	Kürschner-Pelkmann, 2003
dish wash	8	l/cap*day	Kürschner-Pelkmann, 2003
car washing	3	l/cap*day	Kürschner-Pelkmann, 2003
garden area, irrigated	0,1	l/m <sup>2</sup> *day	Koppe, 2006

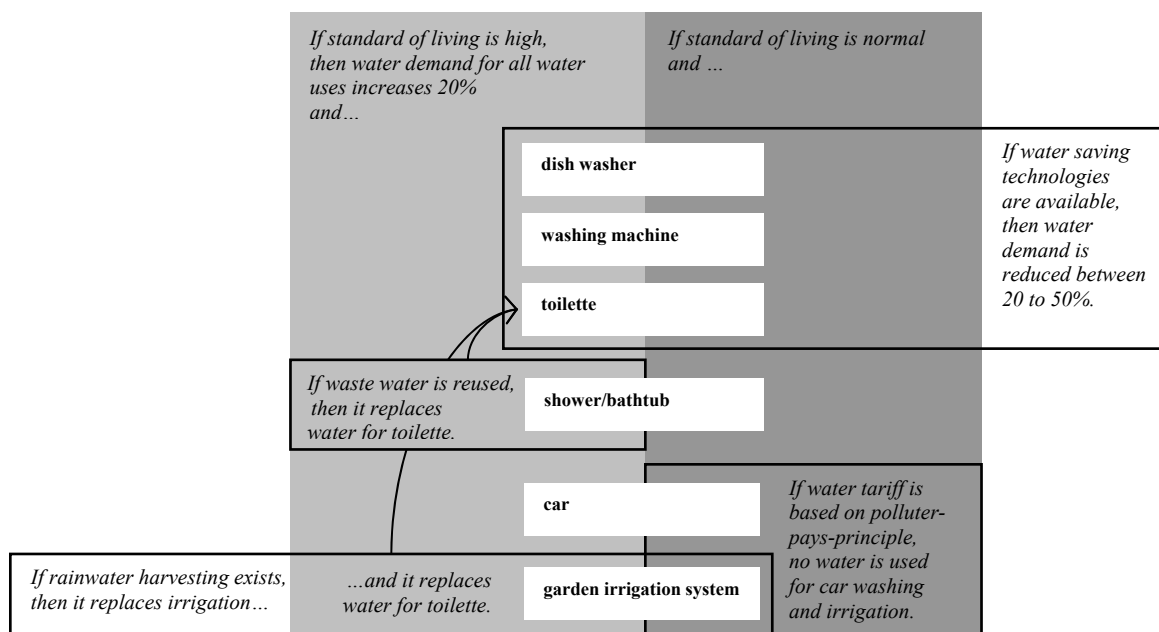
The water demand for irrigating garden area depends on:

- percentage of inhabitants owning a garden around the house
- duration of irrigation period (days per month)
- size of surface area for gardening (m<sup>2</sup> of irrigated garden area per household).

The WBM includes five rules to refine the calculation of water demand. They all could be applied at the same time and the calculation considers the combination of rules.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	25

In the WBM two types of standard of living – high and normal – are defined. The classification of high and normal standard of living needs to be fixed according to the characteristics of the test site and the discussion with stakeholder. If a percentage of persons with a high standard of living is included, the portion of persons with a normal standard of living is automatically calculated. Otherwise, it is assumed that all households show a normal standard of living. It is assumed that persons with a higher standard of living are more likely not to react on a water tariff supporting the polluter-pays-principle (Figure 12). Secondly, the reuse of waste water and the reuse of rainwater for toilettes require additional investment, which is probably only affordable for those with a higher standard of living. Thus both options only affect the water demand of a household with a high standard of living. Finally, it is assumed that due to a higher standard of living more water (+ 20%) is used to fulfil the domestic water needs.



**Figure 13: Rules included in the calculation of domestic water demand**

In the literature there is a discussion on the effects of water tariff on the habits of water use (an overview is provided in Koundouri, 2006). In the WBM two types of water tariffs are distinguished: tariffs that support polluter-pays principle and tariffs that do not support the polluter-pays principle. If either an individual household metering exists or a split between access charge and volumetric charge is introduced, the water tariff is assumed to support the polluter-pays principle.

In the WBM it is assumed that water for irrigation and car washing declines depending on the percentage of inhabitants paying a tariff supporting the polluter-pays principle. Water used to fulfil basic needs is not affected by the type of water tariff (Grobosch, 2003). Persons with a high standard of living will not change their habits for irrigation and car washing (Gordon-Walker and Marr, 2002, Ernst and Schulz, 2005; Martinez-Espineira, 2002; Martinez-Espineira & Nauges, 2004). In the literature it is argued that such tariffs might increase the number of persons using water saving technologies in the future, but as this may have a long-term effect, it is not included in the WBM.

Making use of water saving technologies reduces the water demand because less water is necessary to fulfil a specific need. It is assumed that 20% of the water demand is reduced for dish wash and washing machine and 50% less for toilettes and bathing (Londong et al, 2004). This applies to both types of standard of living.

Reusing waste water does not reduce the water demand because the same amount of water is requested for a specific need, but as water is used several times, less water is requested from the supply network or more water is available within the sector. As the reuse of waste water depends on treatment technology it is assumed that only persons with a high standard of living can afford to implement reusing technologies. The water demand might be reduced for toilettes up to 25%.

Rainwater harvesting, does not reduce the water demand either. It only satisfies the water requirements by abstracting water from a different water source. Thus it only reduces the amount of water that has to be supplied by a collective water supply network. If the percentage of households with rainwater harvesting increases it is assumed that it is used to replace irrigation water. If the water demand for toilettes and irrigation is fulfilled by rainwater, again this applies only to households with a high standard of living because it is necessary to invest in household infrastructure. In all cases replacing drinking water or water from the supply network is limited to the volume of the rainwater collection tank and precipitation. The WBM calculates the amount of collected rainwater and replaces water from the collective or individual supply system depending on the amount of collected rainwater.

### 5.3 Domestic water stress

In order to assess domestic water stress, water demand is compared to the actually supplied water to the domestic sector taking into account all water inputs and water losses. If the volume of water requested by the domestic sector is higher than the supplied volume of water, water stress occurs. Water stress could be mitigated amongst others by

- reducing the water losses of the water supply network
- supporting water saving technologies if the standard of living is high
- changing the water tariff
- reusing water within the domestic sector if the standard of living is high
- not allowing irrigation during dry periods.

### 5.4 Domestic waste water

The amount of waste water depends on the water used in the households. The water inflows to the settlement area are summed up to the amount of waste water.

The quality of the waste water depends on the number of inhabitants in the settlement area and on the amount of waste water. It is assumed that a given emission load per capita per day is produced (compare Table 5) and diluted by the amount of water used in the settlement area.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	27

**Table 5: Example of water demand of domestic sector**

domestic water demand	value	unit	source
COD	120	g/cap*day	BoKu, 2004
BOD	60	g/cap*day	BoKu, 2004
N total	11	g/cap*day	BoKu, 2004
P total	2	g/cap*day	BoKu, 2004
suspended solids	60-80	g/cap*day	BoKu, 2004

The allocation of waste water depends on:

- percentage of inhabitants connected to sewage system
- percentage of inhabitants connected to septic tank
- percentage of inhabitants not collecting waste water.

If the sewage system is connected to a waste water treatment plant, the allocation of waste water to different types of treatment technologies could be fixed. Waste water from treatment plants disposes the treated waste water into a surface river. Non-treated waste water of a sewage system is directly transferred to a surface river. Waste water from septic tanks is assumed to be used or disposed. It is difficult to calculate how much of the pollutants reach a water body after the use or disposal of waste water. Thus the WBM does not transfer the emission load of reused waste water from septic tanks to the environmental sector. But if information is available it could be included.

## 6. Agricultural sector

### 6.1 Water cycle of the agricultural sector

The total amount of water abstracted from the environment is not modelled, but obtained from available data or stakeholder knowledge. The agricultural sector has two main possible water supply networks: a collective and/or an individual water supply system. The individual water supply network is run by individual water users and includes water abstraction from surface water or groundwater by private boreholes. The amount of water is estimated in the transition “individual water supply” by either percentage of farmers using private boreholes and average amount of water from single boreholes or by expert knowledge or based on a rough estimation. The collective water supply system abstracts water from the environment. The possibility of indicating the amount of water obtained from different water resources is given by the first allocation node on the left side of Figure 14.

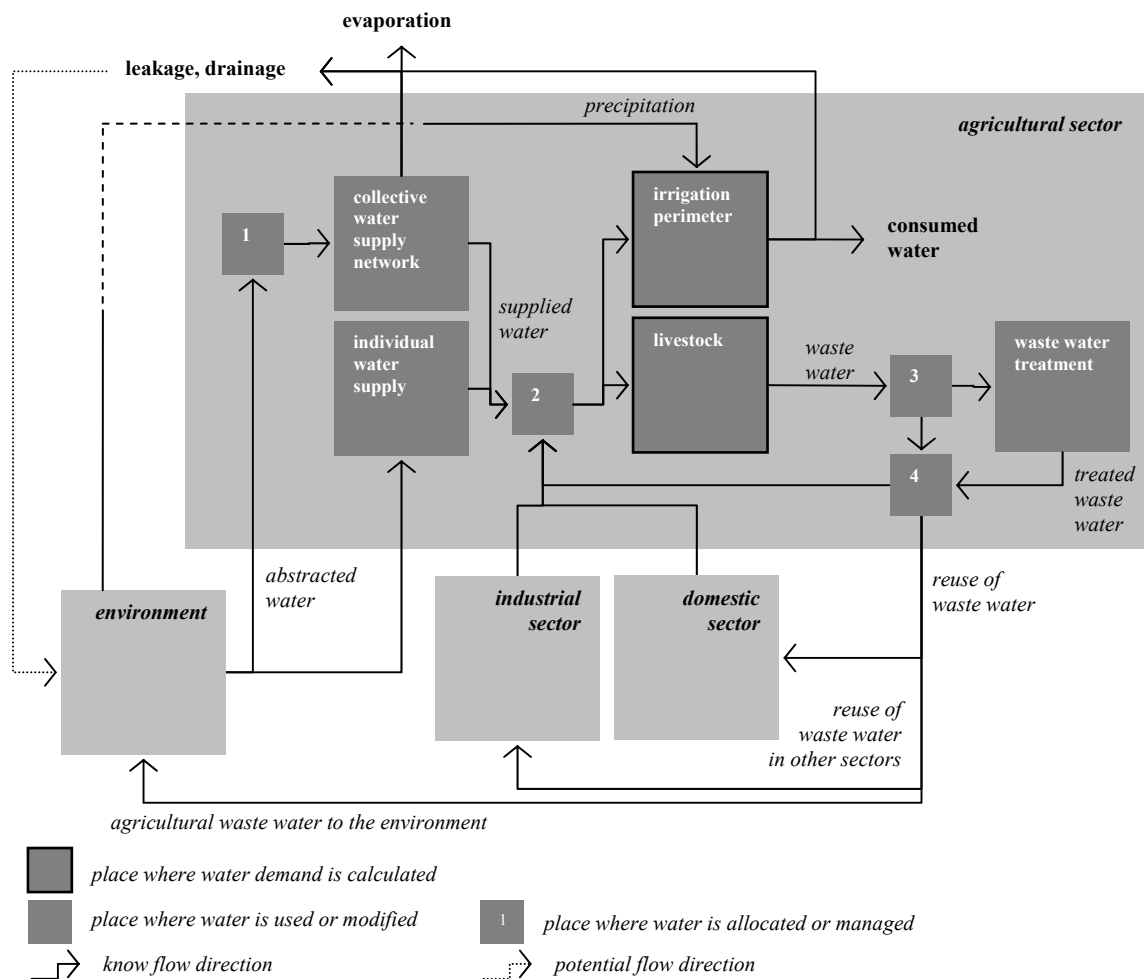


Figure 14: Components of the agricultural sector: input and output water flows of the agricultural sector, allocation of water and places

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	29

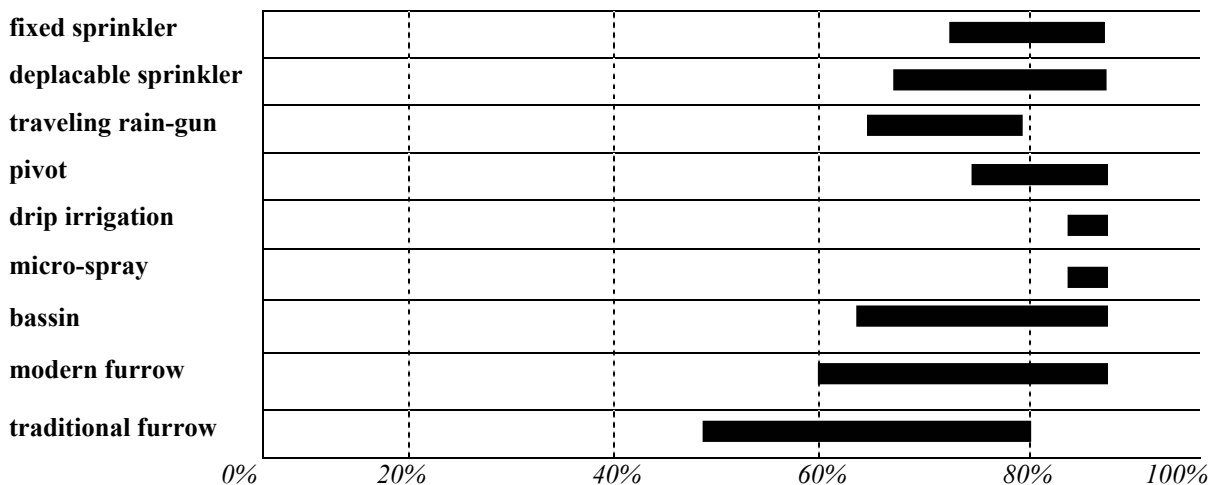
Within the water supply network and in the irrigation system there is often an important loss of water attributable to the distribution system itself, typically due to evaporation and leakage. Depending on the irrigation technique applied on the field, there could be an additional source of water loss. All the water losses due to the irrigation process itself is known as irrigation efficiency. The water losses enter the environmental sector but generally it is difficult to estimate the allocation of water losses to different water sources (to groundwater aquifers or surface water bodies). The water losses due to irrigation supply network and field application is calculated as follows:

**Formula 1:**  $\eta_g = \eta_1 * \eta_2 * \eta_3 * \eta_4$

Where:

- $\eta_1$ : losses (including evaporation) during delivering from storage, dam to border of irrigation perimeter (canals of 1<sup>st</sup> and 2<sup>nd</sup> category).
- $\eta_2$ : losses during water distribution form the border of the irrigated perimeter to the field (canals of 3<sup>rd</sup> category).
- $\eta_3$  and  $\eta_4$ : losses by field application (evaporation of irrigation water and/or irregular distribution of water in soil, and deep percolation, respectively)

For example, in case of traditional irrigation systems with open canals water losses during delivering and distribution ( $\eta_1 + \eta_2$ ) can increase to 70% and water losses by field application can increase to 60% ( $\eta_3 + \eta_4$ ) (Lecher et al, 2001, p. 503ff). In the WBM data on irrigation efficiency of different irrigation systems are used to calculate water losses. Figure 15 provides minimum and maximum field efficiencies according to different irrigation techniques. In case local experience differs from the figures presented, stakeholders' knowledge could be used instead.



**Figure 15: Efficiency level of different irrigation system (Deliverable 2.2-2 of Aquastress project, 2006)**

The type of livestock breeding determines the amount of waste water leaving the agricultural sector. Depending of the reuse objective and on legal requirements a waste water treatment might be obligatory or possible. Additionally waste water from other sectors could be reused in agriculture, e.g. water from hydropower plants might be reused for irrigation. The WBM includes input water flows

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	30

from neighbouring sectors. Depending on the situation in a test site, the amount and the quality of the reused waste water are included.

## 6.2 Agricultural water demand

The agricultural water demand is calculated for irrigation and for livestock. If the amount of supplied water to either one of the two places does not meet the water demand, simplified water stress is indicated. The values used for calculating water demand are based on average data, e.g. crop type data which do not have to be adapted to the test site. If the WBM is applied to a test site, test site specific information needs to be included, e.g. the surface area of irrigated agricultural area or portion of different crop types in an irrigated perimeter.

### 6.2.1 Water demand of livestock

The water demand of livestock is calculated based on the number of cattle and horse in an area and average amounts of specific water demands. The water demand depends on the type of cattle and horse and on the type of cattle breeding. For cattle and horse out at feed the water demand needs to estimate with the help of experts or stakeholder.

**Table 6: Example of water demand of cattle and horse**

agricultural water demand	value	unit	source
cattle and horses	50-60	l/animal*d	Haberl, 2006
cattle breeding without litter	60		
cattle breeding with litter	75		Koppe, 2006
small livestock (flock)	20	l/animal*d	Haberl, 2006
	10-15		Koppe, 2006

### 6.2.2 Irrigation water demand

#### Market gardening

For the irrigation of market gardening area an average volume of water per surface area and day of growing season forms the basis of the calculation. About 0,8 to 1,0 l/m<sup>2</sup>\*day are estimated to necessary to irrigate during the growing season (Koppe, 2006). The duration of the growing season, the surface area used for market gardening as well as the percentage of households with market gardening is used to calculate the irrigation water demand for market gardening. The water used for market gardening however frequently comes from the drinking water supply network.

#### Irrigation perimeter

One of the most important components of the water balance in agriculture is evapotranspiration (Et). Et refers to the process of water transfer from the crop surface to the atmosphere in the form of water vapour. Et is a combination of evaporation, when water is lost from surfaces other than plant tissue, and transpiration, when water losses are mediated by plants. Et is strongly influenced by climate, as this latter determines the temperature and water content of the atmosphere. Reference evapotranspiration (Et0) is calculated from climate parameters as they produce vapour losses from a hypothetical reference crop canopy. Since leaf anatomy and crop canopy aerodynamic properties also

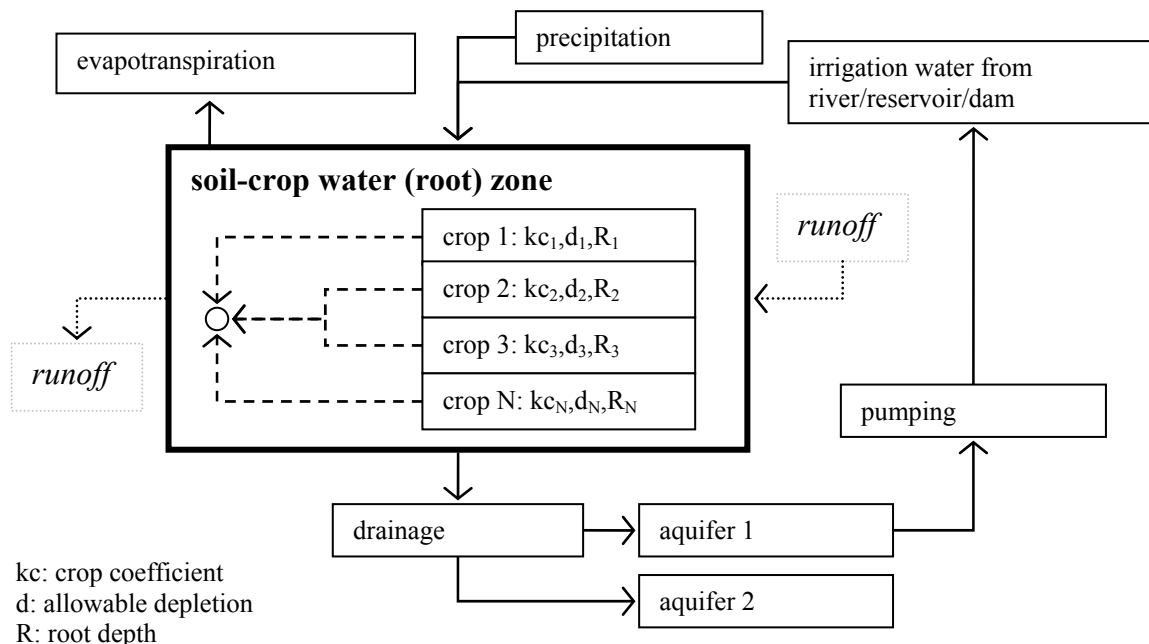
Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	31



affect  $E_t$ , a correction factor ( $K_c$ ) for each crop type is needed to derive the “real”  $E_t$ , the crop evapotranspiration ( $E_{tc}$ ), from  $E_{t0}$  (Allen et al. 1998).

The calculation of the irrigation water demand is organized into three main components: water inputs, water outputs and soil-crop interface water balance (Figure 16). Inputs are precipitation and irrigation. Outputs are drainage (deep percolation) and evapotranspiration. Crop evapotranspiration ( $E_{tc}$ ) is calculated from available reference evapotranspiration information, adapted to specific crop characteristics through the use of crop coefficients at different crop development stages. The other input and output variables are obtained from available databases or publications. Dashed arrows represent the information related to crop characteristics, which are parameters that simultaneously influence different model steps and variables.

The soil-crop interface, or root zone, is the “core” of the model, where the calculations are carried out. Water inputs and outputs are compared with the water soil capacity and crop water needs in order to assess the overall balance. The time scale was set to represent monthly or annual balances, being a month the smallest time unit. The water considered to be available for crop growth is the portion of water in the soil that lies within the root zone (represented by a container in Figure 17). So, the primary determinant of the soil water capacity is the crop root depth. The actual water capacity of the root zone is further determined by restricting the available volume to the soil pores, indicated by the fraction of the pores that can be readily accessed by the roots. The actual water capacity is the volume left after drainage by gravity (at soil field capacity), and that can be extracted before reaching the soil wilting point (Figure 17). An additional restriction to the water availability is the allowable depletion of soil water, which is the point below which water can be extracted by plants, but at the expense of a normal crop yield.



*Runoff is not included.*

**Figure 16: Mechanical representation of the calculation of water demand in an irrigation perimeter**

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	32

The excess water that drains from the root zone as determined by the soil field capacity and goes into a ground water aquifer.

Crop characteristics can be considered a sub-component of the model (linked to the model through dashed arrows in Figure 16). They influence both the root zone water balance and the evapotranspiration, because crop type determines the root depth, the allowable soil water depletion, and the value of the crop coefficients.

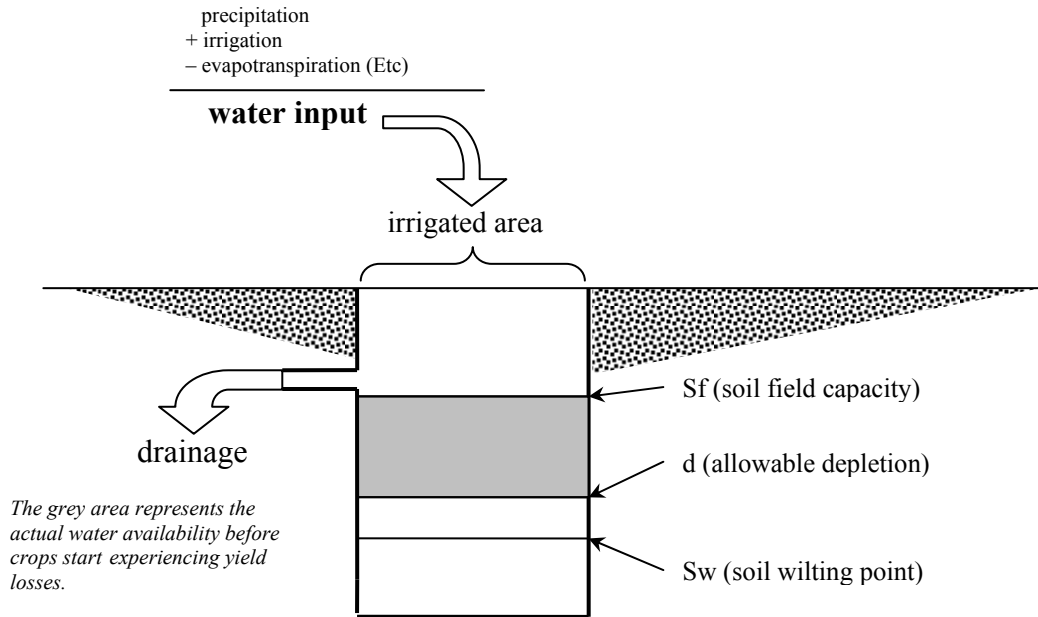


Figure 17: Agricultural water balance model structure

### Irrigation model functional description

The water balance assessment starts with entering the input water (precipitation and irrigation) information at each month of the year (Figure 17). Actual evapotranspiration (Etc) is subtracted from the input water. Etc is calculated as:

$$Etc = Et_0 * kc.$$

$Et_0$  = reference evapotranspiration after Penman-Monteith

kc = crop coefficient is assigned per month per crop

Kc is divided in 4 periods: initial, developmental, mid-season and end-season. If more than one crop is present, the contribution of a monthly Kc from each crop to a “global Kc” is calculated by multiplying each Kc by the fraction area of that crop. The soil water capacity and crop water requirement is calculated by first estimating the average root depth, R, at that month for the whole study area. When more than one crop is present, the contribution of the root depth of each crop to the overall average is represented by a weighing factor determined by the fraction of each crop’s area to the total cultivated area. Then the total soil capacity is multiplied by the fraction number (around 0.4) that corresponds to the soil field capacity (Sf), to estimate the **Maximum water need**. The soil cannot retain more water than its field capacity, thus any amount of input water beyond this volume goes to Drainage (or deep percolation). Sf is estimated based on soil texture, which is a function of the soil type. R is also

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	33

multiplied by a fraction corresponding to the soil wilting point ( $S_w$ ) to calculate the **Minimum survival water need**. The soil fraction provided by  $S_w$  needs to be filled by the input water, but remains in small soil pores and is not available for its use by plants.  $S_w$  is estimated based on soil texture, which is a function of the soil type.

**Table 1: Variables, parameters and model outputs**

symbol	name	source	units
Pp	Precipitation	available information	mm/mo.
I	Irrigation	available information	Mm <sup>3</sup> /mo.
Etc	Actual evapotranspiration	calculated	mm/mo.
Et <sub>0</sub>	Reference evapotranspiration	available information	mm/mo.
Kc	Crop evapotranspiration coefficient	available information	-
R	Crop root depth	available information	mm
Sf	Soil field capacity	available information	-
S <sub>w</sub>	Soil wilting point	available information	-
D	Soil drainage (or deep percolation)	calculated	Mm <sup>3</sup> /mo.
d	Crop allowable water depletion	available information	-
MWN	Maximum water need	calculated	Mm <sup>3</sup> /mo.
MSWN	Minimum survival water need	calculated	Mm <sup>3</sup> /mo.
MOWN	Minimum optimal water need	calculated	Mm <sup>3</sup> /mo.
Stress	Simplified water stress	calculated	Mm <sup>3</sup> /mo.
additional information as input:			
<ul style="list-style-type: none"> <li>• total area of irrigation</li> <li>• surface percent of each crop type per month</li> </ul>			

Between the two fractions already mentioned,  $R \cdot Sf$  and  $R \cdot S_w$ , there is a portion called the **Minimum optimal water need** that represents a certain volume below which the optimal crop yield is reduced. This portion depends on the allowable depletion fraction ( $d$ ).  $d$  is different for each crop type and has a constant value for the entire crop season. An overall  $d$  is calculated by multiplying each individual crop  $d$  by the fraction area of that crop. The model starts with a given amount of water in soil in January. When no previous information is available, it can be assumed that the amount of water at the beginning of the calculation period equals the wilting point fraction of the soil. Then all subsequent monthly calculations are done taking into account the water balance of the previous month. Since at a given month some crops may not be present, the total irrigation volume for that month is distributed only among the crops that are present at that moment. For this reason, we prefer to convert the precipitation and evapotranspiration data from mm to actual volume value of the entire area under study.

### Soil salinity

Salination is particularly problematic in arid climates (Berrkia 2003). The presence of salts reduce the absorption capacity of plants, it reduces the fertility of soils, and could have toxic effects on plants. The irrigation method and the quality of the water used for irrigation can increase or decrease the accumulation of salts in soil. When soil salinity is considered to be a problem in the agricultural system, then corrections to the water inflow are applied accordingly. In general, the need of additional water to attenuate the soil salt content is estimated by accounting for soil salt content and the crop tolerance to salt, as:

$$WS_{sal} = MIN_{opt} \times 1 / (1 - (S_s / (5 \times C_s - S_s)))$$

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	34

$WS_{sal}$ : Water demand due to salinity

$MIN_{opt}$ : Minimum Optimal Water Need

$S_s$ : salinity of irrigation water in dS/m or g/l

$C_s$ : crop salinity tolerance

### 6.3 Agricultural water stress

Although the livestock and the irrigated transitions can be intimately connected, they will be treated as separate modules or systems for modelling purposes, in view of their differences in dynamics and behaviour.

The amount of water stress is estimated separately for each sub-sector taking into account their water demand and supply. The total water availability from the irrigation system is assessed by calculating the difference between the net input water and the soil-crop capacity and need. If the former is lower than the latter, simplified water stress situation is defined, at a value proportional to the amount of water deficit. The resulting stress can be increased leaching water requirement. Finally the values for livestock and the irrigation water demand are added together for a calculation of the whole sector water stress.

However, it is possible to get water stress in such systems where the depletion of the soil-crop-capacity occurs in such a manner that several irrigations per unit of time are needed. The impact of longer irrigation frequencies due for example, to lack of water or lack of management capacities of the network manager will not be taken into account. Due to the temporal system boundaries, the WBM will detect water stress only by comparing averages for single months.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	35

## 7. (Semi-)natural ecosystems

### 7.1 Water cycle in (semi-) natural ecosystems

Like the other sectors, (semi-) natural ecosystems are divided into several types. For (semi-) natural ecosystems this division is based on the main crucial source of water supply: precipitation, (flowing) surface water or groundwater. Water demand is calculated in different ways for these types, and so is water stress. However, all (semi-)natural ecosystems have the same, simple conceptual water cycle in the WBM. The total amount of water flowing through (semi-) natural ecosystems is derived from three sources: rainwater, groundwater and surface water. Consumption of water is limited to evaporation and transpiration by either plants, animals or bare soil. Water that is not consumed remains in the system, except for excess water in rain fed systems, it flows to groundwater dependent systems, or may be allocated over groundwater and surface water dependent systems. If data are available, a flow from surface water dependent systems to groundwater dependent systems (or vice versa) may be defined. The input of rainwater is calculated from the surface of the area and measured precipitation values. The input of surface water and groundwater are all surface and groundwater resources with a water quality that does not exceed certain predetermined limits. Both surface and groundwater dependent systems exchange water with neighbouring areas.

### 7.2 Water demand of (semi-) natural ecosystems

For all (semi-) natural ecosystems the minimal water demand is the average monthly evapotranspiration of the type of ecosystem considered. For entirely rain fed systems, this minimum demand is set as the actual demand. For surface and groundwater dependent systems, however, water demand is higher. Wetlands are usually linked to either surface water or (upwelling or standing) groundwater and thus treated under the respective categories. Similarly, lake water bodies depend typically on either the inflow of water from rivers, or are linked to groundwater bodies.

(Semi-) natural ecosystems that depend mainly on surface water are not necessarily surface water systems. They comprise the different aquatic systems, both in rivers and river-fed lakes, and/or the river or lake marginal wetlands, as well as the terrestrial systems that depend on water from the river, and no distinction is made between them to calculate the water demand. All riverine systems depend on a stream flow pattern that is as close to the natural as possible, with an acceptable water quality. Using local knowledge, this stream flow pattern should be translated in a certain amount of water needed, which constitutes the water demand of all riverine systems lumped. Currently, for all surface water bodies across Europe a reference condition has (should have) been determined for the Waterframework Directive. Using the work that has already been done, the water quality criteria are derived from those reference conditions. Additionally, they can be discussed with local experts and stakeholders. Thus, the water demand is expressed as a certain amount of water with concentrations of pollutants below a certain level. More detail can be added by specifying how much of a certain quality is needed (e.g. xxl of oligotrophic water, yyl of mesotrophic water,...).

Currently the following approaches are discussed:

- Wetlands:  
In order to avoid simplified water stress in a wetland, a defined area needs to be watered: depending on the number of floods per period, the surface area of the wetland and the minimum height of a single flood the minimum quantity of water could be calculated to maintain the ecosystem.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	36

- Surface river:  
The minimum vital flow is used to define the water demand. Information about river dynamics is incorporated in the calculation of this vital flow.

### 7.3 Waste water in the environment

As far as possible the emission loads of waste water from human sectors is calculated. If the waste water is reintroduced into the surface water or groundwater, the concentration of these emissions in the water available to the dependent ecosystems is calculated and could be compared to (EU) standards.

If the flow direction is not known it is also possible to transfer the qualitative information into a quantitative approach by calculating the amount of water needed to dilute the water content pollutants in order to respect standards. In this case the potential impact is estimated. It is based on the assumption that the larger the volume of water to dilute waste water, the higher the potential impact on water resources, the higher water stress due to waste water.

### 7.4 Water stress of (semi-)natural ecosystems

Water stress is calculated for each types of (semi-) natural ecosystem. Thus, one general water stress figure is given for the type for the whole area, without distinguishing between aquatic systems, wetlands or terrestrial ecosystems, or between plants and animals. The main aim of the WBM is to compare sectors by their water stress, not to identify areas of concern to ecologists. The calculation of water stress as proposed here should be sufficient for that goal without adding too much detail or demanding too much data.

As precipitation is currently not impacted by humans in the WBM, entirely rain fed systems are considered not to experience water stress. For surface water systems, the water demand is compared to the availability of good quality surface water. If through mixing or spilling the whole surface water body is contaminated and no distinction can be made between good and bad quality water, the approach mentioned above is used, by adding the amount of water that would be needed to dilute the water to the calculated water demand. In this way, the most concentrated pollutant determines the total water stress.

Groundwater-dependent (semi-)natural ecosystems are only included in the WBM if data are available on the groundwater recharge and groundwater abstraction. Comparing groundwater recharge and groundwater abstraction storage changes are indicated. Negative storage changes are considered water stress because groundwater-dependent (semi-) natural ecosystems are affected. A problem might be that due to uncertainties in the data water stress in groundwater is indicated.

Currently the assessment of water stress is based on an approach that compares standard guidelines for relevant abiotic variables with measured levels. The problem is that it might be difficult to define standard guidelines for all relevant water related ecosystems. Furthermore this approach requires measurements of variables and thus is data intensive. In case no measurements are available water stress cannot be determined. Another approach - measuring the response directly in related ecosystems - seems to be difficult to integrate it in the WBM.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	37

The WBM will also integrate a quantitative approach for assessing water stress but this will be a rather simplified approach which might be useful only for a few types of water-related ecosystems, e.g. for wetlands. In these cases the suggestion is to estimate a water demand in terms of a quantity of water and compare both, the estimated water demand with the actual level of water. An even more simplified approach assumes that any abstraction of water will induce water stress. In this case a summary of all water abstraction for human water uses from natural resources will indicate the water stress for the water-related ecosystems.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	38

## 8. Concluding remarks

The concept of the WBM is being developed by a recurrent expert consultation within WB 2 while the water stress index was being discussed. The discussion of the water stress assessment in the single sectors and the perception of water stress by different stakeholders profited mutually from other WB 2 activities. Furthermore, a part of the draft of the concept was presented in WB 4.

While discussing the concept of the WBM one of the test sites, the Tadla irrigation perimeter in Morocco, was chosen to test a selected sub system of the model – the agricultural sector. For the next working period, all sectors of the selected test site of the WBM will be calculated. As the (semi-) natural ecosystem is partly still under discussion the main focus will be to refine the water stress calculation for this sector.

It is also possible to test the use of the model in a decision making process in one of the selected test sites. This will need to be coordinated in close cooperation with one of the joint working teams. This seems to be necessary because the WBM might lead the discussion back to the identification of causes of water stress and thus could hinder the progress of the case studies. Besides, it is currently discussed to use the results of the WBM to support one of the case studies in Tadla (linking agent-based model with a water balance).

If the stakeholders evaluate the WBM as overall 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 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 the all sectors. The calculation of the industrial water demand takes into account the state of the art in different industrial branches and refers to European experiences. In this sector it might be necessary to adapt the approach to test sites. The calculation of the agricultural water demand is always accompanied by uncertainty because a lot of information is needed and some of the most influencing factors are difficult to estimate. The WBM considers the most relevant factors and became rather detailed compared to other sectors. But still the results will have to be discussed with the stakeholder 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.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	39



The presented WBM is intended to represent a useful tool to stimulate discussions on water management and allocation among stakeholders, as well as make explicit which gaps in knowledge are currently impairing real integration of water management over all sectors.

Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	40

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Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	41

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Doc Name: Deliverable ID: D2.3-1 doc	Date: 19/9/2006
Dissemination level: PU – final report	42