Report on indicators for water stress. AquaStress D2.1.3 - Final report

C. Sullivan, M. Manez, S. Schmidt, E. Moors, E. Preziosi, Sébastien Loubier, D. Inman, K. Tarnacki, I. van den Wyngaert, A. Olsthoorn, et al.

AquaStress

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

Integrated Project

D 2.1.3

REPORT ON INDICATORS FOR WATER STRESS

Author(s): C.A. Sullivan[1], M. Manez[2], S.Schmidt[2], E. Moors[3], E. Preziosi[4], S. Loubier[5], D. Inman[6], K. Tarnacki[7], I van den Wyngaert[3], A.F.M. Olsthoorn[3], Jochen Fröbrich[8], Bettina Blümling[2],P. Koundouri[9], S. Panebianco[2], A.M. Giacomello[1], Dirk Günther[2], and David Jones[1]

Contact for queries: Dr. Maria Manez

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[1] Centre for Ecology and Hydrology, Wallingford UK
[2] USF – University Osnabrück, Germany
[3] Alterra, Netherlands
[4] IRSA- Rome, Italy
[5] CEMAGREF, Montpelier, France
[6] University of Cranfield, UK
[7] University of Aachen, Germany
[8] University of Hannover, Germany
[9] Department of Economics, University of Reading, UK.

SUMMARY

This report provides a detailed overview of the development of an integrated tool for evaluation conditions of water stress, to be referred to as the Aquastress Water Stress Matrix (AWSM). This tool combines a selection of information relevant for water management decision making, and has at its core, a composite index of water stress, here referred to as the Aquastress Water Stress Index (AWSI). In addition to this composite index, the details of this index are presented in ways that can be visualised, as a means of overcoming the problem of providing complex water stress information as a single number. The framework allows including further information for decision makers within this matrix, like mapped and photographic evidence relating to the specific site under examination, as well as guidance, using a traffic light approach, on the urgency of the situation.

After a brief reminder of the objectives within the Aquastress project, underlying assumptions and a glossary of terms are presented. Some detail is then provided on the structure and various parts of the Aquastress Water Stress Matrix. A detailed explanation is given on how the Aquastress Water Stress Index is calculated, and how it is to be interpreted to provide an insight into the nature of the water stress problem at the site in question. Through an examination of the sources of water at the site, this index can be used to evaluate water stress in a test site as well as in so called sectors like industry or agriculture. It aims at identifying causes of water stress and interdependencies between water uses and water resources. In addition, the sectoral information provided in the index, and related suggested methodology to include thresholds, assist the users to identify possible stress mitigation options. The discussion of potential sectoral variables to be included in the AWSI is included in the text.

The process of application and use of the Aquastress Water Stress Matrix (and its core index) is then presented. This provides some guidance on the procedure to be followed in implementing this tool, and it also suggests roles for both practitioners and stakeholders in this process. Some tentative conclusions and recommendations for next steps are provided.

As a way of supplying additional supplemental information to the reader of this report, a number of appendices are added. These address the definition and classification of indicators and indices, data requirements, and technical issues concerning weighting and standardising of component scores. Problems such as double counting, determination of thresholds and interpretation of indices are considered. Conventional approaches to assessing water stress and existing in-use indices are briefly reviewed, and a brief overview of relevant issues at the Aquastress test sites is presented.

There is no doubt that the task to develop an effective and holistic measure of water stress is a complex one, but such a tool has an important role to play in decision-making for Integrated Water Resources Management. This will be of use as it will provide water managers and stakeholders with a common knowledge base, making comparisons between different places and conditions more meaningful. This is particularly necessary where water has to be managed in transboundary basins, and it will also provide the basis on which temporal comparisons can be made to assess progress in the water sector.

Managing social, economic and natural resources in such a way as to ensure that future generations have the same level of opportunities as current generations is a crucial challenge for sustainable development. This means that the spatial, temporal and social tradeoffs must be

considered and managed within the constraints of the physical and social systems. This forms the basis of our design of the water stress index for the Aquastress project.

In the development of the Aquastress Water Stress Index (AWSI), therefore, we are aiming to capture the range of issues relevant to the test sites, and from these, create a composite framework which will help to identify the causes of water stress. In order to capture and deliver a broader range of information than can be provided through a mathematically based index, we then combine this index with other, more qualitative issues, in the format of a Matrix, which is designed to provide a useful set of information for management and policy purposes. The criteria for measuring which information is useful for such purposes are determined by what is:

- politically relevant / relevant for decision makers
- scientifically valid and reliable[10]
- easy to explain / to understand

This last criterion is crucial when information must be delivered to politicians, the press and the general public, as required in any process of water management. In keeping with the objectives of the project overall, it is hoped that this work will be of use to the wider public in the EU, and may become applicable in areas outside of the test sites. For this reason we are aiming to produce a generically applicable tool, but for the purpose of the Aquastress project, it is hoped that this Aquastress Water Stress Matrix will be useful for determining the degree of water stress in the test sites. Moreover the matrix could be useful to those who wish to determine what solutions should be applied to the specific needs of each site, thus providing a link between WBs 1 and 3.

[10] Validity measures the degree to which an indicator represents the characteristic it claims to, and reliability indicates that the indicator will represent that characteristic repeatedly over time.

Glossary of terms and definition of words used in this report as result of WB 2 work

AQUASTRESS WATER STRESS INDEX (AWSI) - a composite index to assess water stress, developed for the Aquastress project

CATEGORY – a specific dimension of each component included in an index (four all together: quantity and quality, capacity, infrastructure and social and economic equity)

COMPONENT – a specific section within a composite index

COMPOSITE INDEX – an index constructed by combination of a selection of individual parts or components

FORMULAE – the mathematical structures by which components are combined to form an index

INDICATOR – a specific piece of information or data which represents a specific issue or condition

INDEX – a mathematical structure by which different information is combined – usually based on indicator data (difference between formulae and index is not clear, but I guess that this is based on Carolines suggestion… I would have used other definition:

index: mathematically aggregated/built number derived from a series of observations or data or components, used as an indicator or measure (might sound very Sonja….)

INFRASTRUCTURE – constructed application of physical technology

INSTITUTIONAL AND ADAPTIVE CAPACITY – ability of organisations and individuals or groups to adapt to changing conditions

INTEGRATED SECTORAL WATER STRESS INDEX (ISWSI) – a composite index representing water stress in different sectors, combined to give an integrated evaluation

MATRIX – a combination of information to provide an integrated and holistic set of knowledge on which decisions can be made

NATURAL BASELINE ENDOWMENT- this takes into account all the parts of the water balance which are naturally available due to effective precipitation inside the test site area, as well as all the water flows which enter naturally into the system: river discharge from upstream, groundwater flow (potentially usable), spring discharge, etc. including both renewable surface water and groundwater

POTENTIAL MARGIN – this is a measure of how close a water system is to reaching the limits of its natural baseline endowment

SECTOR – part of economic activity representing different water uses (includes the environment)

SOCIAL AND ECONOMIC EQUITY – a state resulting from the equitable distribution of resources between different members of society

VARIABLE – a number representing a specific indicator

WATER STRESS - condition in which water demand exceeds water supply. This has been defined specifically in WB2 as Water stress occurs when the functions of water in the system do not reach the standards1 (of policies) and/or perceptions (of the population) on an appropriate quantity and quality, at an appropriate scale and the adaptability for reaching those is not given[1].

WEIGHTING – the degree of importance attributed to a specific component or variable, within a mathematical formula

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1 INTRODUCTION

The development of an index of water stress, based on the development of a list of indicators as well as on the framework for the construction of an integrated/composite index is a key part of the work in WB2 of the Aquastress project. This has been considered to be an important output of the project, given the increasing incidence of water stress across Europe and other parts of the world. Furthermore it combines the results of WB 1 with the work in WB 3 as it is based on data characterising the water stress situation in the test sites (WB1) and helping to define potential case study areas (WB3). How this fits with the rest of the project is illustrated in Figure 1 and Table 1

Figure 1: Linking issues in the Aquastress case studies (after J. Froehbrich)

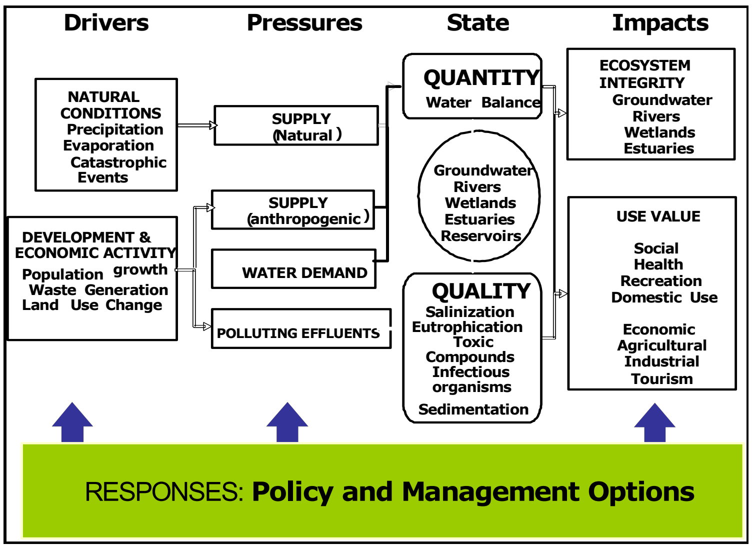


Table 1: Potential mitigation options within the Aquastress project

Technical options		**Non-technical options**	
I Domain: Increasing water availability	WP 3.1 **- Alternative water sources**	*III Domain: Supporting change*	WP 3.5 - **Incentive mechanisms for balancing demand and supply**
	WP 3.2 **- Integrated management of surface/groundwater**		WP 3.6 **- Institutional analysis**
II Domain: Water saving	WP 3.3 **Technologies for water saving**	*IV Domain: Decision support for planning*	WP 3.7 - **Procedural methods**
	WP 3.4 **- Practices for water saving**		WP 3.8 **- Supporting sciences**

This output has been the result of a wide range of inputs from several project partners representing a number of different disciplines. It has been a produced attempt to offer a new approach to the problem of water stress assessment. An index-based approach has been chosen to provide a rapid appraisal methodology for application by stakeholders.

It is not intended that this approach should in any way replace conventional hydrological modelling or other water stress assessment techniques. It is intended to provide an analytical tool which enables a holistic evaluation to be made enabling better understanding of a complex situation which cannot easily be measured. It is hoped that this will be of use as a heuristic tool, to promote discussion by different groups of stakeholders. As such it can be described as a decision support tool which will function through the provision of a standardised set of relevant yet diverse information about the *conditions underlying the required water management decision*.

1.1 Rationale

Water stress is a global problem with far-reaching economic and social implications. The mitigation of water stress at regional scale depends not just on technological innovations, but also on the development of new integrated water management tools and decision-making practices. The Aquastress project delivers enhanced interdisciplinary methodologies enabling actors at different levels of involvement and at different stages of the planning process to mitigate water stress problems.

The Aquastress project will generate scientific innovations to improve the understanding of water stress from an integrated multisectoral perspective to support:

- diagnosis and characterisation of sources and causes of water stress;
- assessment of the effectiveness of water stress management measures and development of new tailored options;
- development of supporting methods and tools to evaluate different mitigation options and their potential interactions;
- development and dissemination of guidelines, protocols, and policies;
- development of a participatory process to implement solutions tailored to environmental, cultural, economic and institutional settings;
- identification of barriers to policy mechanism implementation;
- continuous involvement of citizens and institutions within a social learning process that promotes new forms of water culture and nurtures long-term change and social adaptivity.

The project adopts a Case Study stakeholder driven approach and is organised in three phases:
(i) characterisation of selected reference sites and relative water stress problems,
(ii) collaborative identification of preferred solution options,
(iii) testing of solutions according to stakeholder interests and expectations.
It will make a major contribution to the objectives of the Global Change and Ecosystems and supporting the Community Directive 2000/60/EC and the EU Water Initiative.

WB 2 in the Aquastress project is to determine a methodology to assess water stress. We have developed an integrated index for this purpose, and we have set it into the context of a matrix, to provide more comprehensive information through which decision makers can be better informed.

1.2 Assumptions behind the work presented

In work of this type, it is important to consider the assumptions behind the design of the matrix and tools suggested here. The main assumptions are as follows:

- **water is a necessary factor of production** for all human activities, and is an essential component of the global life support system. We recognize therefore that water acts as a constraint in our system.
- **human activities inevitably impact on the environment** (through entropy) and for sustainable water management to be achieved, this must be managed within the boundaries of what are defined by society as acceptable risks (acceptability determined through participation of stakeholders). In the construction of the AWSI and AWSM, this will be addressed through thresholds where relevant.
- **market forces usually determine how resources get allocated within human systems,** and these market forces have sometimes to be modified by legislation, as a result of the externalities that market impacts create. (Market failures).
- **the democratic process determines that all sectors of the economy and society should have equal access to the use of any resource,** within the constraints of markets. This means that for the purpose of determining a baseline measure, we will assign an equal degree of importance (weighting) to each of the major components of the index we are developing. This will ensure that equal emphasis is placed on all sectors (this will avoid dominance of water allocation decisions by economically and politically powerful interest groups).
- **the determination of weightings can be modified** according to specific priorities of the location in question, and this may be implemented for actual decision making, rather than simple site comparison.
- **weightings can be changed to reflect national priorities**, but they must be determined by government and stakeholders in consultation to ensure the process is transparent and acceptable. Where index values are to be used for comparison, weightings will all be kept at parity.

1.3 THE CONCEPT OF AN AQUASTRESS WATER STRESS MATRIX

During the process of the literature review carried out during this project, and building on earlier work on index development by Aquastress project team members, it had been observed that there was some dissatisfaction in the use of indices in general. Statements are sometimes made about an index being too simple, or not comprehensive enough, with the methodology not allowing a sufficient breadth of knowledge to be included. While some of these criticisms may not be justified, it was decided early on during the work of WB2 to enrich the index concept through additional material relevant to the evaluation of water stress in any location. As a result, it was decided that the index developed in the project should be combined into a more comprehensive matrix structure, to provide a richer knowledge-base as a tool for decision support. This matrix structure would provide a vehicle through which data from the Aquastress Water Stress Index could be visualised within the context of other visual material, provided in a comprehensive, standardised structure. This Matrix would be compiled in a convenient format, so that decision makers and other users could all have easy access to the relevant and available information, thus providing a heuristic tool through which consultative dialogue could be conducted. Under conditions of water stress, this would be a valuable tool as it would allow stakeholders with different perceptions to be presented with a rich and standardised set of information.

1.3.1 Composite indices as holistic tools for water management

While existing indicators may be of some use for sectoral planning, or for meeting specific legislative criteria, (e.g. for the WFD), the development of a new, specific and targeted index for water stress in the context of Europe and North Africa, will contribute to the potential for more holistic and integrated water resource management in that region. In this report, the Aquastress WB2 team is attempting to build on these indicator concepts to develop an integrated index, capturing a wide range of issues to represent a more holistic picture of the water stress problem. Water is regarded as a limiting factor in economic development when national withdrawals exceed a certain percentage of annual internally renewable resources. Water scarcity is worsened when a country falls in the category of low-income developing countries, because lack of financial, technical, and other capacity give rise to a particular vulnerability to problems caused by water shortages. As a way of assessing these more complex issues, the Aquastress Water Stress Matrix (AWSM) is being developed, along with its related Index (AWSI) and it is hoped that this matrix, and index, through testing at the diverse Aquastress case study sites, will become robust and accepted as tools for integrated water management and macroeconomic planning across the European Community and beyond.

1.3.2 The concept of DPSIR in indicator development

A framework for water indicators in the European Union has been developed (Jesinghaus, 1998), and this has been the foundation for many indicators developed subsequently using the DPSIR approach. The DPSIR approach has become widely used to developing indicators. It is based on the concept that change occurs over a period of stages, which have been identified as:

- Drivers
- Pressures
- States
- Impacts
- Responses

In this approach, it is assumed that all aspects of any environmental change can be placed within one of these stages, and by identifying these stages, we are able to better represent what may be needed as an appropriate response. As a general framework, this can be used theoretically to characterize and manage any kind of environmental problem (Dhakal and Imura 2003, Odermatt 2004).

The DPSIR approach has been widely applied to many kinds of problems, in coastal environments, including bays and estuaries (Jorge et al. 2002, Bidone and Lacerda 2004, Cassazza 2002); river basins (Dietrich et al 2004, Walmsley 2002); or a combination of both (Trombino et al. 2003); groundwater studies (Cools et al. 2002), and wetlands (Turner at el. 2004)

Arguments have been made (European Environment Agency 1999), that the DPSIR approach permits the establishment of causal relationships between human activities, their environmental impacts, and the effects of societal responses. It is certainly true in some cases, that such cause and effects can be known (e.g. the link between lead emissions to the environment, and its impact on human health), and effective policy responses have been the result (e.g. the removal of lead from petrol).

Despite the great number of studies that utilize DPSIR as an analytical framework, few reports explicitly address its advantages. These studies seem to exclusively agree on its ability to organize and present environmental problems, and to help scientists and managers to think about processes in terms of causality (Jorge et. al 2002, Caeiro et al. 1999, Turner et al. 2004). Since DPSIR requires the establishment of causal relationships between sequences of indicators, it can be of great use where these are known, and in such cases, it undoubtedly constitutes an improvement over use of simple environmental indicators or aggregates of indicators, which may represent an over-simplification of the problem. There are however many cases where the issue to be managed within the environment is so complex that such a simple classification is rather meaningless, since the cause and effect linkages are not known. For the DPSIR approach to be really effective, accurate data, knowledge of dose response relationships, and observable measures of appropriate parameters are all needed, but unfortunately, all too often, these conditions do not exist.

A number of authors have put forward several disadvantages of the DPSIR approach. In some cases, isolated chains of indicators may not be enough to reproduce the complexity of systems (Bassel 1999, Rekolainen et al. 2003, Caeiro et al. 1999, Jorge et al. 2002), which tend to behave more like a network rather than a linear chain. Also, the need to assign a specific role (driver, pressure, state, etc.) to environmental indicators induces the creation of static categorizations, whereas in reality, for example, under certain conditions a response can become a driver.

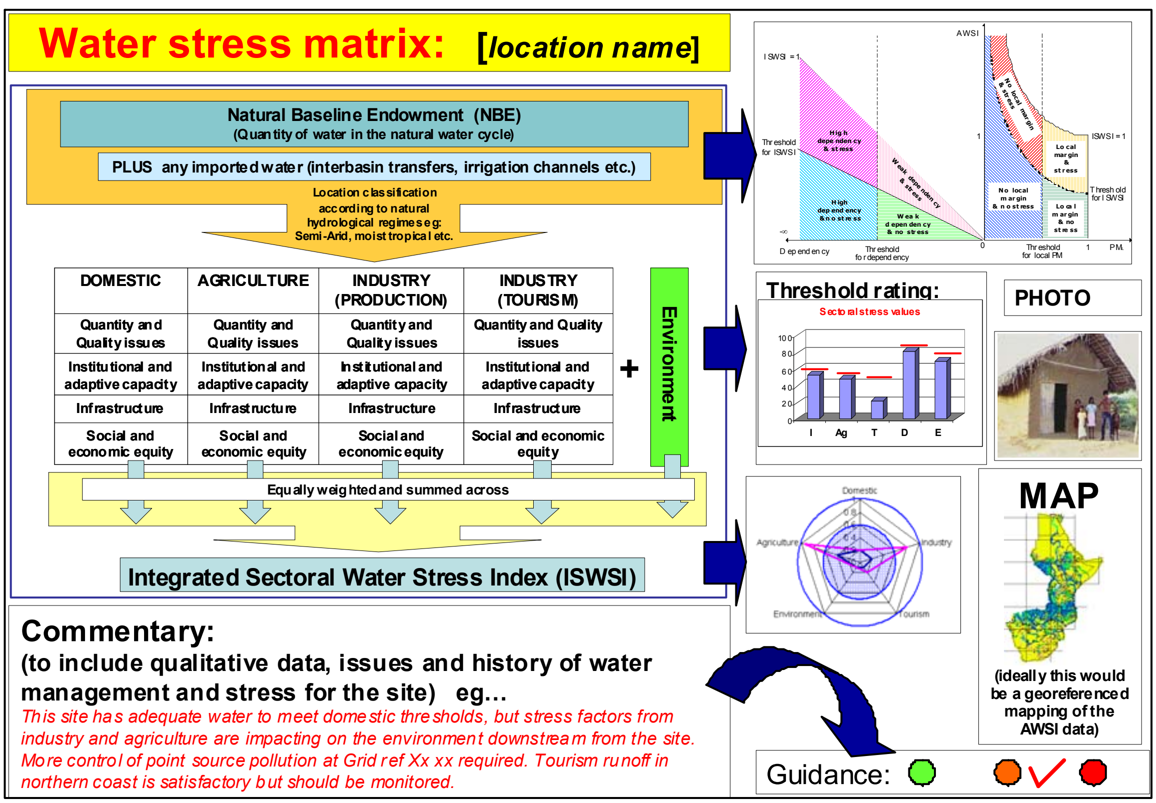
In the case of the work done by Sullivan et al, (2002, 2003, 2005, 2006), on the development of the Water Poverty Index (WPI) and Climate Vulnerability Index(CVI), these problems have been avoided, by both not being tied to the DPSIR structure, and by being based on an analytical hierarchy after Saaty (1980). The Analytical Hierarchy approach of Saaty also provides the analytical framework for the Aquastress Water Stress Index. The structure suggested in this report goes beyond the DPSIR approach, by specifically linking supply and demand, and including a range of related linkages.

2 THE STRUCTURE AND COMPONENTS OF THE AQUASTRESS WATER STRESS MATRIX (AWSM)

2.1 Introduction and rationale behind the water stress matrix

As explained in the previous section, the reason for building a matrix of information and knowledge, rather than simply providing a simple index value, is to provide all stakeholders with relevant information in an open and accessible way. Since it is widely recognised that knowledge is power, it is felt in this work that the conversion of disparate data into comprehensive knowledge is a worthwhile effort, and the dissemination of that knowledge to a wide range of users in an easy to understand way is a prerequisite for promoting more equitable decision making. Knowledge cannot always be quantified in such a way as to be used in a mathematical way, and so the use of a matrix as a vehicle for combination of different sorts of information will enable the knowledge generated through it to be more holistic and covering various disciplines. Furthermore this approach has the advantage that it takes into account not only hydrological and/or physical aspects of defining water stress but also social and economic dimension of water stress. An example of the format of the Aquastress Water Stress Matrix with its various knowledge attributes is shown in Figure 2.

Figure 2: The format of the Aquastress Water Stress Matrix (WB2-advances)



2.2 Water stress quantified in the Aquastress Water Stress Matrix through the use of a composite index

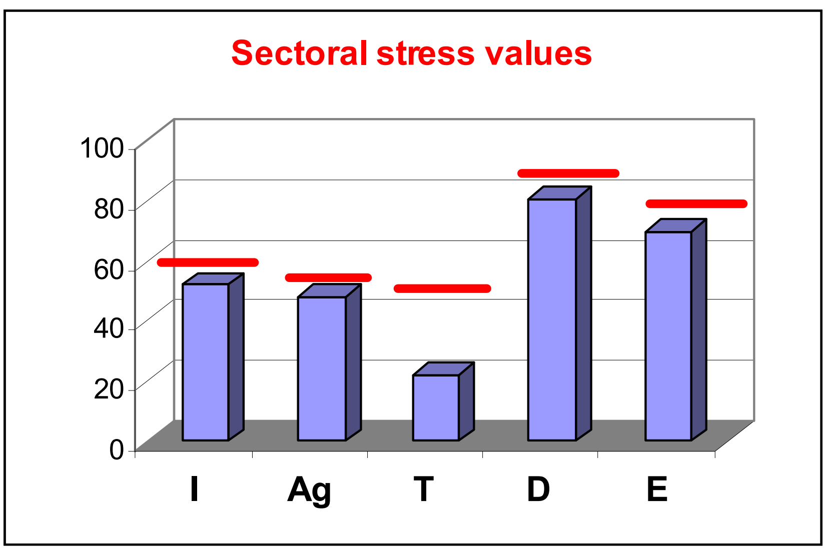
Key elements of information needed to quantify water stress can be integrated through the mathematical framework of a composite index. This index is referred to here as the Aquastress Water Stress Index, and it forms an essential element of the AWSM. The values generated by this index provide the foundation of how the level water stress at any site can be evaluated. This level of water stress will be determined by an interaction of the supply of water (both local and imported), and the demand for that water from different sectors. A detailed explanation of how this index is calculated is provided in Section 3 below.

2.3 Threshold scores for index component values

Using thresholds

The Aquastress Water Stress Matrix will contain a lot of useful information for water managers and other decision makers. It will provide a numerical assessment of the degree of water stress existing at the site, and it will suggest from which sectors the stress is coming from. Further discussion will be needed on issues concerning interpretation, but at this stage, we suggest that thresholds are useful as a form of guidance for the interpretation of some of this information. The concept of thresholds is illustrated in Figure 3, which shows a set of hypothetical values and thresholds for the five component scores of the ISWSI. In the case shown, each component remains below the threshold, so the point of stress has not been reached in any sector. Some comments on how this may be addressed in the Aquastress project are provided in Figure 3.

Figure 3: Sectoral stress values



Determining the thresholds: the example of the domestic sector and the environment

The concept of thresholds is discussed in the section on the structure of the AWSI, but it important to consider thresholds from different points of view. With regard to domestic thresholds - for the most simple measures (e.g. per capita water availability, or per capita consumption) demand thresholds will be is specific to a particular region, so applying a generic threshold may be problematic. If we want to understand the efficiency of use, that is simpler because we can use existing accepted standards, such as those relating to minimum requirements provided by Gleick, the WHO, Shuval etc. (see Domestic Sector report in D2.1-1).

The proportion of water used for domestic purposes varies considerably between the different Aquastress study sites. For example, in the Guadiana case, domestic water use accounts for only 4 - 5% of total water use, rising to 9 -10% of the total water use in the Algarve, which takes account of tourism. In Flumendosa, domestic water use accounts for around 40% of total water use; while in Iskar, domestic water use accounts for 70%.

Considering that domestic water stress (due to water scarcity) is a real problem in all of these basins, and the proportion of domestic water use varies from 5-70% , using the proportions of sectoral water use alone cannot serve as a suitable threshold for indicators of water stress. An interesting activity would be to compare the fraction of sectoral water use (domestic, agriculture, industry, environment) with the total water exploitation index (WEI). This will indicate competition for water between sectors, as well as water stress in individual sectors, providing a kind of 3-dimensional analysis. This, along with year on year trends in sectoral uses (i.e. are they increasing or decreasing), would reveal interesting information. Thresholds also need to be identified for the environment sector, but this is not a simple task. The environmental indicators that have been defined are meant to indicate the severity of problems impacting on the environment. This includes indicators on the risks and quality of natural ecosystems. If water availability would normally limit growth in dry ecosystems, this is not considered water stress according to the definition in the project. In the project, as indicators of this type are only defined to describe water stress on a larger scale. When the water quality in a river is low, this means a threat to downstream nature reserves, e.g. Ramsar sites. This is also considered as water stress in this project.

In the case of the environmental indicators, values are compared with EU guidelines, when available. Most often these EU guidelines are described in the national reports that are made for the Water Framework Directive (WFD). These values from the WFD reports will be used to determine thresholds, e.g. for toxic substances in surface water. When no WFD reports are available for the sites (Bulgaria, Tunisia, Morocco), other indicators have been defined that are more easy to calculate. For these sites, local thresholds will be used, when available. The local thresholds might be defined through stakeholder agreement, but we will also compare these values with the WFD thresholds for a comparison between the sites. Sometimes, gradual changes in an indicator indeed point out a gradual increase of the environmental risk. Then a threshold for sudden increase of risk cannot be given, or only after comparisons of all indicators for all sites. In the site reports (Deliverables 2.2-2), the comments on the values for the indicators will be based on these assumptions.

For most indicators, a higher value means a higher environmental risk. In some cases, a higher value means a lower environmental risk (this is usually done by using the reciprocal of the value to indicate a negative relationship). This has to be taken into account when making calculations for combination of indicators, e.g. within an index or a matrix.

In a similar manner to the domestic and environmental sector, it could be possible to generate sectoral thresholds for agriculture, industry and tourism, but this is a slow process and finally defined thresholds are not yet available. In these cases it is necessary to define thresholds for each test site.

2.4 Graphical representation and interpretation of the water stress index

The computed value of the AWSI can be illustrated through a graph. This is described in detail in section 4. The illustration of the AWSI has been discussed within WP2.1 but the suggestion for it comes from CEH.

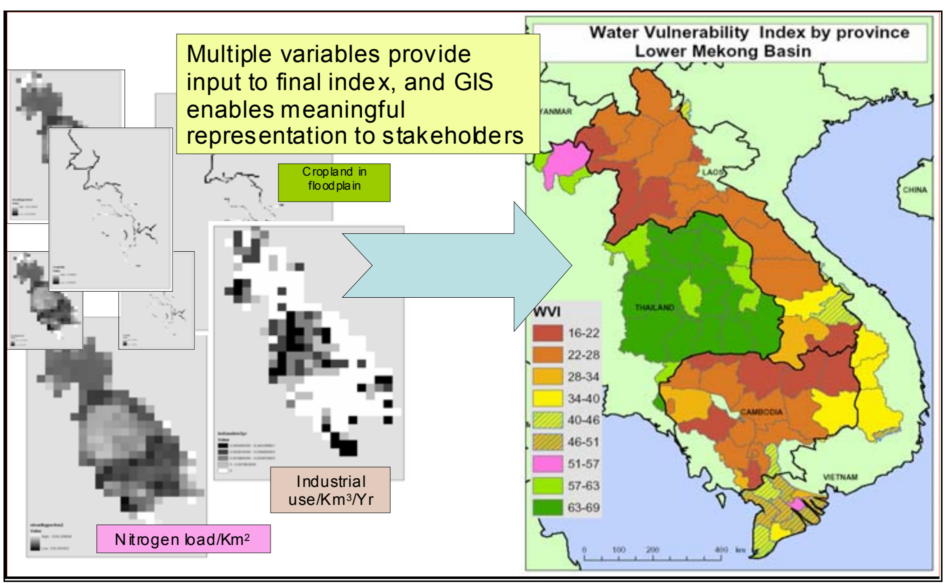
2.5 The provision of additional qualitative knowledge through a commentary

The commentary is to provide the opportunity to include non mathematical information about the site, and any additional information, perhaps from local knowledge, for example. In some places this information may be more useful than the calculated AWSI, and combined with the other parts of the Matrix, it can be of use in a qualitative way. This section could however also provide other scientific information, including references to additional documentation etc.

2.6 Geographical information and maps

By geo-referencing and digitizing the data going into the calculation of the AWSI, it is possible to generate maps indicating diversity of AWSI scores across a region or even a basin. This is illustrated in Figure 4, showing Water Vulnerability Index scores for the lower Mekong.

Figure 4: Example for geo-referenced results: Water Vulnerability Index Scores displayed through GIS



Source: Sullivan et al., 2006. GWSP working paper 1.

In the test sites, the extent to which georeferencing of data is being carried out is not clear The development of this type of approach to water assessment in the case study sites will result in the potential development of an integrated dataset on which this analysis is based. One of the real advantages of this approach is that it can draw on both new data, and existing data, for example drought maps developed in previous studies could be an important source of information in some areas. While this may not be possible in the test sites at this time, WB2 recommends that this should be done where possible.

2.7 Application of the Aquastress Water Stress Index and Matrix in the test sites

As part of the activities of the Aquastress project, it is anticipated that the developed index and matrix methodology will be applied in the test sites. This will not only provide a means of testing the index methodology itself, but it will also serve to enable joint work teams from the test sites to evaluate the situation in the site, and lay the foundation for future monitoring of water stress within the site.

The potential to do this will depend on the availability of relevant data at the test sites, and in some cases this may be only be available with difficulty. While it is the intention to apply this standardised analytical framework to as many test sites as possible, this may not be achieved, and as a result it may be necessary to compute a base line for the purpose of cross-site comparison, with a more site-specific model to be applied for local decision-making purposes. This approach is what is being recommended here in this report. To illustrate the variability within Aquastress test sites, some basic information about the sites are presented in Appendix.

3 POTENTIAL SECTORAL VARIABLES FOR INCLUSION IN THE AWSI

Following list of indicators was created during several working sessions of the participant institutions of WP 2.1 (see annex E). First based on expert knowledge indicators have been collected to indicate water stress in each sector, the domestic, industrial and agricultural sector as well as for the environment. The industrial sector is divided into two parts as both show different characteristics: production and tourism/services. The tourism/services resemble the domestic sector and are often included in the domestic water infrastructure. On the other hand the water demand of the tourist sector might play an important role in some test sites and therefore should not be included in the domestic sector but examined additionally. The list of indicators has been structured according to the aspects: water quality and quantity, institutional and adaptive capacity, infrastructure, society and equity. Finally the list of indicators has been reduced by ranking the indicators of each category using two criteria: relevance and data availability. The decision has been taken that the first four indicators of each category in each sector should be used in each test site. It is a broad list of possible indicators that has to be adapted to the particular conditions of the test-sites and to the availability of data. Main idea of the list was to create an inventory of indicators that could be used in the test-sites of Aquastress.

3.1 Sectoral indicators

3.1.1 Domestic sector indicators

NOTE +ve values means increase in water stress, negative value means a reduction in water stress

1. Quantity & Quality

1. Per capita consumption (litres/capita/day) variation over the last 10 yrs *(an increase in consumption +ve)*
2. % Domestic consumption as a fraction of the total (i.e. industry + agriculture + domestic + environment etc)
3. Population density (inhabitants/km^2) variation over the last 10 years *(higher is more stress)*
4. no of days per year when e coli thresholds are exceeded in any water body within the administrative unit

2. Institutional and adaptive capacity

1. Per capita investment in demand management and water treatment (e.g. raising public awareness raising, water saving schemes, new treatment plants) and domestic water stress mitigation each year for the last five years (*more budget allocated per capita means there is more need for mitigation indicating the existence of water stress, but at the same time, investment indicates a higher level of institutional capacity).*
2. Existence of a national water regulator to oversee implementation of national laws to promote demand management and better water quality.
3. multiple billing scales to promote water conservation (eg changes in seasonal charges) *Y/N – yes means water stress exists so classed as +ve*

3. Infrastructure

1. Supply interruptions - % time without water supply per connected household per year over

the last 10 years *(higher % more water stress, therefore +ve)*

2. % Losses in infrastructure network
3. Number of days per year when water is supplied by tankers or requires additional filtration/boiling *(high number indicates stress, so +ve)*

4. Society & equity

1. Percentage of average per capita earnings paid as water bill
2. % of population who have no formal access to water supply of any type (high numbers suggest higher water stress, +ve)
3. % of population within the administrative unit reporting incidents of water related diseases (diahoreea, etc) (not malaria) *(high number of cases of water disease suggests higher water stress so +ve)*

3.1.2 Agriculture

NOTE +ve values means increase in water stress, negative value means a reduction in water stress

1. Quantity & Quality

- The ratio $\frac{irrigated\ \ area}{agricultural\ \ area}$ is a basic indicator of water dependability. It can also be an indicator of agricultural vulnerability according to the distribution of the irrigated area. It is then recommended to assess the part each type of crops (cereals, fruits, vegetable, permanent grassland and fodders) represents within the irrigated area. This ratio could illustrate the current effect of agricultural policies (CAP in Europe) where an increase in irrigation is encouraged by specific crops subsidies. A high value of the ratio is associated to a potential high water stress and farm vulnerability to water conditions changes. Inversely, a low value is associated to a low water stress and vulnerability.
- The ratio $\frac{Water\ \ Supply - Crop\ Water\ \mathrm{Re}quirement}{Crop\ Water\ \mathrm{Re}quirement}$ illustrates the real crop water stress. A negative value of this ratio is associated to a positive water stress and a negative value to a low or absence of water stress. The more the negative value of the ration is high, the more it is exists chances of high water stress situations. A negative value can be considered as an output, i.e. a stress coming from the agricultural sector and potentially supported by all sectors, whereas a negative value can be considered as an input of water stress to the agricultural sector mainly coming from other sectors or from physical natural characteristics like rainfall…
- The irrigation seasonality indicator, $\left(1 - \frac{average\ weekly\ irrigation\ demand}{higher\ weekly\ \ peak\ irrigation\ demand}\right)$, represents a potential water stress within a season. A value of the indicator near zero is associated to a low intra-annual water stress and a value near 1 to a high impact on water stress.
- The dependency of agriculture to irrigation can also be an indicator of potential water stress. The indicator proposed is expressed as $\sum_{j=1}^{j=5} \frac{(yield\ \ per\ non\ irrigated\ \ hectare)_j}{5.(yield\ \ per\ \ hectare\ irrigated)_j}$, where "j" are the five types of crops presented above. A high value of the indicator (near 1) is associated to a low potential water stress whereas lower values (near 0) are associated to a rather high one.

- The $\sum_{i=1}^{i=4} \frac{(real\ water\ quality)_i}{4.(required\ water\ quality)_i}$, illustrates the dependability of irrigated agriculture to water quality. The components of the quality can be phytosanitaries products, salt contents, heavy metals and organic matters and the required quality defined as standards accepts for irrigation. A value of the indicator higher than 1 is more subject to be associated to a high water stress and a lower value to a less water stress situation.

2. Institutional and adaptive capacity

1. The percentage of farmers with secondary level of education is supposed to be more aware of the potential damage they could generate or of the existence and possibilities to access new technologies. This is the assumption underlying this indicator. A high value will then be associated to a low water stress and values near zero to a potential high water stress.
2. The percentage of farmers receiving eco-money (environmental payments, labelling…) either from public authorities or from private companies (farm-produce companies) can reveal a propensity of farmers to develop sustainable practices. Thus, a high percentage of farmers receiving eco-money can be associated to a low impact on water stress and a low value to a rather high potential impact on water stress.
3. The percentage of the irrigated area using water saving technologies (drip irrigation for example or rain gun instead of gravity), reveal an adaptation to a water stress. A value near zero reveals either an absence of water stress or an absence of adaptive capacity to a water stress what lead to an increase in potential water stress. A value near 1 reveals a rather high adaptive capacity of farmers and potentially a lower water stress
4. The percentage of farmers' members of a formal or informal cooperation of farmers (sharing machineries, staff for commercialisation, lands…). a high percentage reveal a rather high adaptive capacity and are more likely subject to develop effective water management options.

3. Infrastructure

1. The percentage of the irrigated area that is under water management (control of water consumption) can be an indicator of potential water stress; a high value being associated to a low water stress and a low one to a high potential water stress because of the absence of water management. For this indicator, it is considered to take into account the irrigated area under management scheme (gravity and pressurized networks) and the irrigated area depending on self supply and equipped by water metering.
2. The indicator dependability of supply $\left(\frac{actuel\ interval\ between\ deliveries}{planned\ interval\ between\ deliveries}\right)$ can also reveal water stress situations. A value below 1 is associated to a potential high water stress either because of water shortage or because of network management deficiencies and a value upper than one is associated to a rather good situation in terms of water availability for irrigation.
3. The percentage of the irrigation potential defined by the agricultural or hydraulic regulation that is really used by farmers $\left(\frac{irrigated\ area}{potentially\ irrigated\ area}\right)$ It is an indicator of potential water stress when the value is greater than 1.
4. When collective systems exist, the fees recovery rate can be an indicator of potential water stress. The opposite diagram illustrates the potential effect of an increase of the unpaid fees rate. Let suppose that because of a service quality inadequate to farmers' demands or because of other external constraints (market prices…), the willingness to pay for that service

decrease and generate unpaid fees, the network manager will suffer from an increase of the administrative costs, will then either increase the water price or reduce some operation and maintenance activities, what will lead to a reduction of the service quality, an reduction of the distribution effectiveness and so on. Face to a low service quality, farmers can decide to disrespect allocation rules (water turns, water robs…) based on hydraulic constraints, and then to water wastes. The unpaid fees rate regroups several components that can potentially reveal and have an impact on water stress. The more the unpaid fees rate is high, the more the system studied is likely to face water stress.

4. Society & equity

1. The proposed indicator is based on the assumption that farm size dispersion reflects revenues dispersion. Knowing that this assumption is wrong for a comparison between irrigation farms and non irrigating farms[11], the two systems are separated. The indicator consist in comparing, for irrigated farms and dry ones, the average size of the first smaller quarter farms to the average size of the fourth quarter and to weight it by the percentage the area concerns represent within the whole agricultural area. It corresponds to the following indicator: $\frac{Q_{1,i}}{Q_{4,i}} s_i + \frac{Q_{1,d}}{Q_{4,d}} s_d$ Where : Q1 is the average size of the first quarter and Q4 the size of the fourth quarter; indices "d" and "i" indicating respectively dry or irrigated; "si " the area dominated by farming systems (respectively "j" for dry systems). Note that a farm having both irrigated and dry area will be fully counted in "irrigating farm".
2. $\frac{subsidied\ irrigated\ crop\ area}{irrigated\ area}$ or $\frac{subsidies}{agricultural\ revenue}$ a high values can be associated to potential water stress. This is mainly a socio economic indicator of policy intervention in agriculture. We assume that a value of the indicator near 1 is more subject to be associated to water stress since it exist distortions in the allocation of factors of production (this is for example the case of the CAP in many European country that favoured maize crops production to the detriment of water availability). A value near zero will be associated to a low impact on water stress.
3. The committed water is that part of outflow from the basin or defined domain that is committed to other uses such as downstream environmental requirements or downstream water rights[12] . It then exist committed water from other basins (entering in the basin studied) and committed water for other basins (going out the studied basin). An expression of this indicator can be: $\frac{Committed\ water\ (from\ and\ for\ other\ basins)}{Annual\ water\ ressources}$ A basin is then vulnerable from the water stress point of view when it is largely dependant on the committed water from other basins and when other basins depend on "their" committed water (the underlying assumption is that the studied basin does respect the commitment). See for definitions of the terms employed.

[11] In France for example, to get the same revenue in dry farming systems compared to irrigated one, it is necessary to have an area twice superior.

[12] The uncommitted outflow is the water that is not depleted, nor committed and is therefore available for a use within the domain, but flows out of the basin due to lack of storage or sufficient operational measures. Uncommitted outflow can be classified as utilizable or non-utilizable. Outflow is utilizable if it could be used by improved management of existing facilities.

3.1.3 Industry-production

In this case, the impact on the water system in terms of outputs and inputs, has been identified.

NOTE +ve values means increase in water stress, negative value means a reduction in water stress

Quantiy & Qualtiy

Quantity of water (annual amount) also taking account of variability and quality (how suitable for purpose)

- Volume of industrial water abstraction from public water supply & private wells as a proportion of available water/abstraction (+ve shows water stress) (relevant, data not yet completely available for all test sites) INPUT/OUTPUT
- Specific Contaminant load as a result of industry (Δt COD/ € GDP) (+ve shows water stress) in proportion to river flow (very relevant, data not available and not always free for public) OUTPUT

Infrastructure

- % of manufacturing units abstracting water directly from rivers (+ve shows water stress) (relevant, data not available) INPUT/OUTPUT
- % recycled water use by industries compared to total recycled water use (-ve shows water stress) problematic? Recycling coefficient within a company (how much of the total water flow is recycled) (very relevant, data not yet available) INPUT/OUTPUT

Institutional and adaptive capacity

- % of manufacturing units with own water treatment plants to ensure the quality of water inputs (+ve – shows water stress) proxy for quality of water & costs occurred (very relevant, data not yet available) INPUT
- % of manufacturing units with the labelling-EN ISO 9001 (-ve more water stress) (not so much relevant, data not available) OUTPUT

Society and equity

- Difference in % of SMEs and % of non-SMEs without guaranteed delivery agreement (shows where the water stress hits hardest) (not so much relevant, data will not be easy to get) INPUT
- Total (percentage) loss in manufacturing revenues due to cut offs (+ shows water stress) (relevant, information will be difficult to get) INPUT

3.1.4 Industry -Tourism / Services

Note: Tourism is considered separately from other forms of industry due to the difference in its impacts on stress

Quantity & Qualtiy

Quantity of water (annual amount) also taking account of variability and quality (how suitable for purpose)

- total number of tourist overnight stays per year (higher number = +ve)
- number of litres of bottled water used in tourist sector
- % of water used by tourist sector from the public distribution system (since for both sectors we indicate water stress, we do not have to do it through an interlinkage again, but higer % = +ve = more stress)
- % change in population at peak tourist season compared to local population based on census figures. (high percentage = more stress - +ve)
- Volume of water used by tourism (higher volume = more water stress - +ve)

Institutional and adaptive capacity

- % of hotels having information to avoid misuse of water / to avoid the waste of water (higher % indicates water stress - +ve)
- % of water recycled on-site total compared ot total water used
- % of hotels having any water-saving techniques (higher % = reduction in stress -ve)
- % of hotels having rainwater-harvesting (higher percentage = less water stress –ve)
- % of business units receiving any environmental certification (-ve)

Infrastructure

- % of hotels having desalination or filtration systems on-site compared with hotels having these systems 10 years ago (higher percentage = less impact on water sytem so -ve)

Society and equity

- tourism sector turnover/M^3 (higher value per M3, better water use so -ve)
- ratio of tourists to local residents (%) (High ratio of tourists to residents = stress so +ve)

3.2 Environmental components for each sector

(ENVIRONMENT – applicable worldwide)

<u>NOTE +ve values means increase in water stress, negative value means a reduction in water stress</u>

WATER QUANTITY

- annual groundwater abstraction as percent of (10 years average) annual recharge (P) (*+ve, i.e. more is more water stress*) (m3 year-1 / m3 year-1)

• surface water low flow: nr of days of flow lower than 7Q10 low flow; for ephemeral streams: duration of dry period compared to 10 years mean (P) (+*ve, i.e. more is more water stress*) • surface water high flow (flooding): nr of days higher than 7Q10 high flow (flow (P) (-*ve, i.e. less is more water stress*) • locally generated information on changes in the water table
WATER QUALITY (neighbour effects = integrated over upstream area) • Volume of untreated waste water (industrial + domestic + tourism) as % of total run-off (data from other sectors) : proxy for load, load itself would be better but very difficult (D) *(+ve, i.e. more volume of untreated waste water is more water stress*) (m3 / m3) • Diffuse eutrophication: Agricultural fertilizer use in the catchment (total N and P / ha catchment) (D) (+*ve, i.e. more agricultural fertilizer use is more water stress*) (• Diffuse toxic substances: pesticide use in agriculture per ha of agricultural land (substances site dependent-locally relevant) (D) (+*ve, i.e. more is more water stress*) • Hazards with toxic substances: frequency of excedance of a set concentration of hazardous substances (concentration and substances determined by stakeholders/based on (inter)national limits) (P) (+*ve, i.e. more is more water stress*) • Others, General physical-chemical characteristics (WFD) (P), including thermic, oxygen Salinity, Acidity, and Nutrients
INSTITUTIONAL AND ADAPTIVE CAPACITY(= vulnerability of state determining potential impact of pressures on (semi)natural ecosystem) • Surface protected by treaties / total catchment surface (R_) (+*ve, i.e. less is more water stress*) (ha / ha) • existence of laws relating to water and environment - for discussion: how to measure / how to quantify or scale? (data from site partners) • % of wetland area (not) protected by treaties (use local definition of wetland) • (data from site partners) • total number of endangered or endemic species that depend on aquatic/wetland habitats for at least part of their life cycle (=> possibility for recolonization), or • total number of species that are represented by more than 1 % of their total European population in the area at any time (analogue to bird habitats) • (data from European reporting or national/local nature protection agencies) • budget spent on management & restoration of wet ecosystems (data from local/national organizations) (data from European reporting or national/local nature protection agencies) • budget spent on management & restoration of wet ecosystems (data from local/national organizations)
Infrastructure (pressure of water resource on (semi)natural ecosystems) • Number of dams without fish elevators (as proxy for degree of river fragmentation) (data from site partners) • % of total length channeled water course (as proxy for integrity and contact between aquatic and river marginal systems) (data from site partners)

<u>Some additonal notes on environmental indicators</u>

- do not include impact assessment (environmental impact assessments of options) in water stress assessment
- there should be a clear separation between core set of (generic) indicators for all sites, and an additional set of more site specific indicators (more extensive, may need more elaboration) as basis for stakeholder discussions in sites

- In quantity estimates, deviation from normal conditions for:

    - 1) groundwater
    - 2) surface water low flow (refuges)
    - 3) surface water high flow (flooding)

Recommendation: impact on wetlands included in weighting of flooding, additional indicator for impact on wetlands (drainage, ….)

- Volume of untreated waste water (industrial + domestic + tourism) as % of total run-off (data from other sectors) : proxy for load, load itself would be better but very difficult
- Non point eutrophication: Agricultural fertilizer use in the catchment (total N and P / ha catchment)
- Non point toxic substances: pesticide use in agriculture per ha of agricultural land (substances site dependent-locally relevant)
- Hazards with toxic substances: frequency of exceedance of a set concentration of hazardous substances (concentration and substances determined by stakeholders/based on (inter)national limits)
- Algal blooms: proxy for eutrophication, but also problems with toxic algae and consequences of algal blooms (anoxic circumstances)
- surface water low flow: nr of days of flow lower than 7Q10 low flow; for ephemeral streams: duration of dry period compared to 10 years mean (P) (*+ve, i.e. more is more water stress*)

4 STRUCTURE AND CALCULATION OF THE AQUASTRESS WATER STRESS INDEX (AWSI) - Suggested by the CEH team of WP 2.1

4.1 The objective of the Aquastress water stress index (AWSI)

The task to develop an effective and holistic measure of water stress is a complex one. In the project so far, considerable progress has been made in reaching agreement on the conceptualisation and structure of the Aquastress Water Stress Index. Workblock 2 has so far discussed many different ways of developing a comprehensive measure of water stress which can be used in the Aquastress case studies. The first stage of this process was to identify an agreed definition of Water Stress for the Aquastress project. The definition selected, after consultation with the wider Aquastress team members, is as follows:

Water stress occurs when the functions of water in the system do not reach the standards[13] (of policies) and or perceptions (of the population) on an appropriate quantity and quality, at an appropriate scale and the adaptability for reaching those is not given.[14]

As far as possible, this definition has been considered by WB2 when constructing the Aquastress Water Stress Index (AWSI), and the associated Aquastress Water Stress Matrix (AWSM). Within this framework, the objective the Aquastress Water Stress index (AWSI) has been designed to show the level of water stress across the different sectors within a test site; and at the same time to derive the level of dependency on water imported from outside and the local safety margin that a local site can still provide to overcome the water stress problems. This section describes the calculation and structure of the AWSI specifically.

4.2 The proposed structure and components of the Aquastress water stress index (AWSI)

The AWSI is generated through a combination of two parts: the *Integrated Sectoral Water Stress Index* (ISWSI), which is the part of the AWSI able to capture the level of water stress resulting from sectoral demand, and the *Potential Margin (PM)*, which is an assessment of the available water resource supply. The potential margin indicates the degree of dependency on local and imported water, and the safety margins remaining available. By combining these two together, the AWSI is derived as follow:

$$\mathrm{AWSI} = \frac{\mathrm{ISWSI}}{\mathrm{PM}} \qquad [1]$$

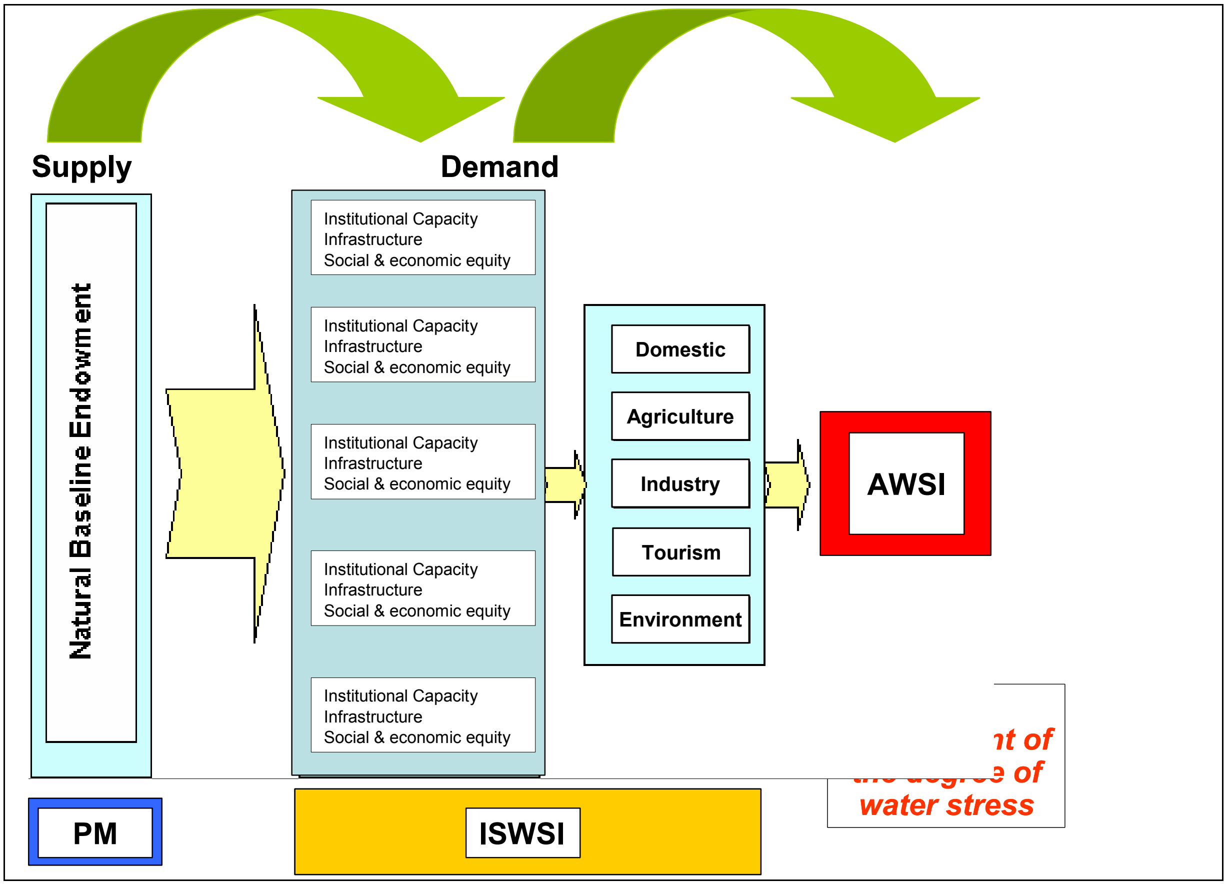
The two components of the AWSI thus incorporate the demand and the supply elements of the water situation, and are represented respectively by the ISWSI and Potential Margin (PM). This is

[13] 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 can not talk, the political bodies for ecosystems would be NGO as well as any scientific publication

[14] The election process for this definition is documented in the annex to deliverable D2.1.1 to be found in the internal AquaStress webpage.

illustrated conceptually in Figure 5, and the sections that follow explain in detail how the ISWSI and PM are respectively described.

Figure 5: Components of the AWSI



4.3 The Integrated Sectoral Water Stress Index (ISWSI)

The *Integrated Sectoral Water Stress Index*, (ISWSI) shows the level of water stress across the different sectors and the type of stress associated with each sector. The major anthropogenic sectors to be considered within water management decisions are: domestic, agricultural, industrial, and tourism[15]. In addition to these four sectors the environment is included, to ensure that a certain degree of water is allocated to the environment to enable ecological integrity.

For each of these five sectors the possible sources of stress have been identified and summarised in three categories:

- institutional capacity,
- infrastructure and
- social and economic equity.

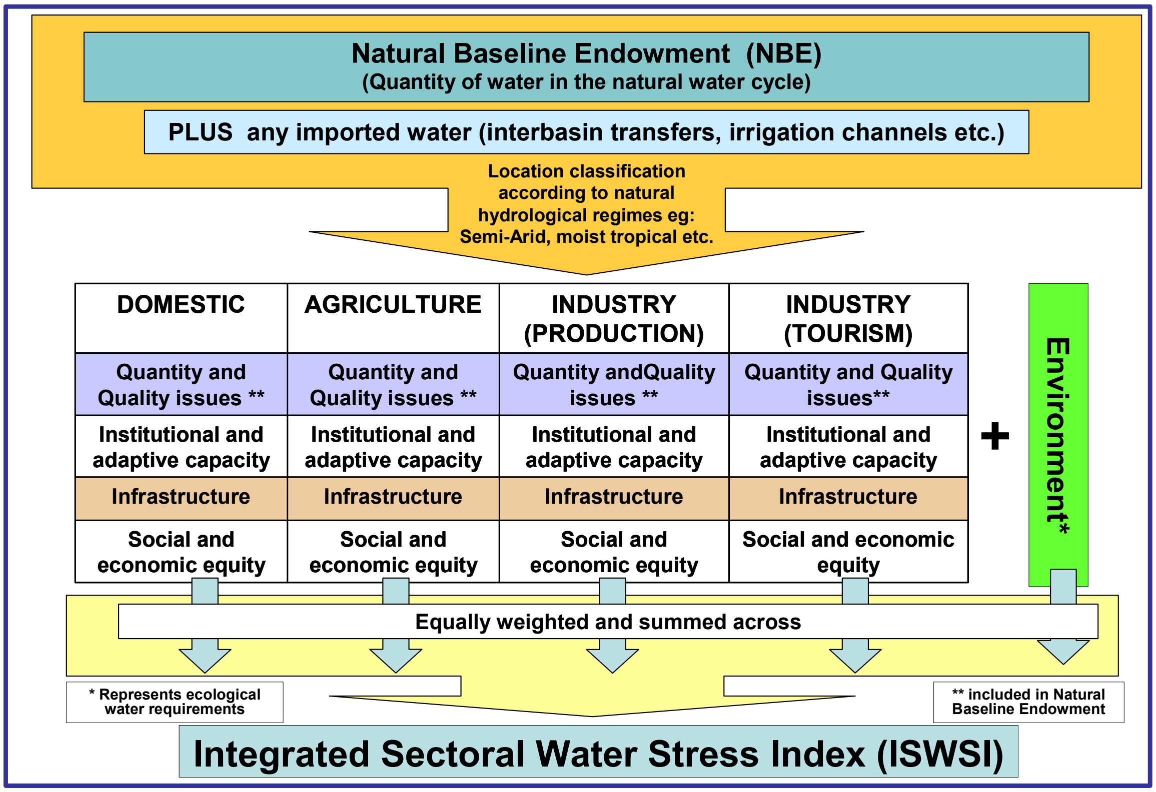
[15] Tourism includes also services.

A sample selection of indicators for these combined attributes of water stress is illustrated in Table 2, and the structure of the ISWSI is shown in Figure 6. As shown in this table, each of these sources of stress can be represented by different indicators.

Table 2: Selected indicators for potential inclusion in the ISWSI

	ENV INTEGRITY	DOMESTIC WATER	AGRICULTURAL WATER	INDUSTRIAL WATER (PRODUCTION)	INDUSTRIAL WATER (TOURISM)
Institutional and adaptive capacity	Surface protected by treaties / total catchment surface (*+ve, i.e. less is more water stress*) (ha / ha)	Per capita investment in demand management and water treatment (e.g. raising public awareness raising, water saving schemes, new treatment plants)	The percentage of farmers with secondary level of education is supposed to be more aware of the potential damage they could generate or of the existence and possibilities to access new technologies. A high value will be associated to a low water stress	% of manufacturing units with own water treatment plants to ensure the quality of water inputs (+ve – shows water stress) proxy for quality of water & costs occurred	% of water recycled on-site total compared to total water used
Infrastructure	Volume of untreated waste water (industrial + domestic + tourism) as % of total run-off (data from other sectors) : proxy for load, load itself would be better but very difficult *(+ve, i.e. more volume of untreated waste water is more water stress*) (m3 / m3)	Supply interruptions - % time without water supply per connected household per year over the last 10 years *(higher % more water stress, therefore +ve)*	The indicator dependability of supply $\frac{\text{actuel interval between deliveries}}{\text{planned interval between deliveries}}$ can reveal water stress situations.	% of manufacturing units abstracting water directly from rivers (+ve shows water stress)	% of hotels having desalination or filtration systems on-site compared with hotels having these systems 10 years ago (higher percentage = less impact on water sytem so -ve)
Social and economic equity	% of total length channeled water course (as proxy for integrity and contact between aquatic and river marginal systems) (data from site partners)	Percentage of average per capita earnings paid as water bill	Committed water is that part of outflow from the basin or defined domain that is committed to other uses such as downstream environmental requirements or downstream water rights. Water coming from other basins, must also be included, and an expression of this indicator can be: $\frac{\text{Committed water (from and for other basins)}}{\text{Annual water ressources}}$ This indicates waterstress downstream, but not fort he testsite in Agriculture Is this an example of double counting in ISWSI and PM?	Difference in % of SMEs and % of non-SMEs without guaranteed delivery agreement (shows where the water stress hits hardest)	ratio of tourists to local residents (%) (High ratio of tourists to residents = stress so +ve)

Figure 6: Structure and Components of the ISWSI



The ISWSI has been constructed using is a composite index[16] approach as shown in Equation 2:

$$ISWSI = \frac{w_D I_D + w_{Ag} I_{Ag} + w_I I_I + w_T I_T + w_E I_E}{w_D + w_{Ag} + w_i + w_T + w_E} \qquad [2]$$

Where w_i is the weight given to the sector i. We agreed that $0 < ISWSI < 1$

I_i is the water stress index for each of the component sectors, ie. Domestic (D), Agriculture (Ag), Industry (I) Tourism services (T) and the Environment (E).

The structure used here is that used in the construction of any composite index. The indicators are first normalised and then aggregated to form a *Sectoral Water Stress Index.* By integration of these five components and 3 categories, it means that overall, to construct the ISWSI, 15 indicators will be needed. Each of the sectoral water stress indices is also a composite index, made up of the three selected indicators, and for simplicity equal weight[17] is applied to each of them.

[16] The composite index is a weighted average. There is also the possibility of developing a non-linear format, and some discussion of this is illustrated in the attached appendix. It is suggested here that the linear solution is the most accessible by users, and so we prefer the formula shown here.
[17] For details on weighting, see Section 3.5.

Each of these sectoral water stress indices, I_i, is made up of at least one indicator from each of the following area: 1) institutional capacity, 2) infrastructure, and 3) social and economic equity. A complete list of suggested specific indicators is provided in Appendix. The recommendation of WB 2 to the test sites is that the required total of 15 indicators (5 components x 3 categories) should be selected (by JWT and stakeholders), where possible from this list in Appendix, and this should form the basis of the specific AWSI for each site. If there are significant data gaps at a site, proxy values can be provided using expert opinion, until such time as an appropriate specific indicator becomes available. The Aquastress indicator team, represented by the authors of this report[18], will be at hand to provide guidance when needed during this process.

To ensure comparability across sites, the same indicators and same number of indicators will be required. This will be difficult to achieve for all the sites, so to test the approach a reduced set of indicators will be used. WB2 propose that a core set be agreed upon by case study partners, and this be used as the basis for comparative purposes across sites, but the set identified by the JWT, in consultation with stakeholders, will be used for local application and use.

During the test site application process, autocorrelation between the indicators will also be tested, which could further reduce the final number of indicators to be used. It should be noted that this should be seen as an iterative process, with refinement of this structure achievable if needed during the site testing process. Since the structure of 15 indicators suggests that the sensitivity of the model to any one indicator will be relatively small, slight variations in any one of the indicators chosen should not create a significant impact on the overall ISWSI score.

The determination of the core set will be the result of further consultation within the overall project team, but one suggested possibility could be that selection shown in Table 3.

Table 3: A suggested core set of indicators for cross site comparison

Domestic	Agriculture	Industry (Production)	Industry (Tourism)	Environment
Supply interruptions - % time without water supply per connected household per year over the last 10 years *(higher % more water stress, therefore +ve)*	$\frac{WS - CWR}{CWR}$ where *WS* = water supply *CWR* = crop water requirement The ratio above illustrates the real crop water stress. A negative value of this ratio is associated to an increase in water stress, and a positive value to a low or absence of water stress.	Volume of industrial water abstraction from public water supply & private wells as a proportion of available water/abstraction (+ve shows water stress)	ratio of tourists to local residents (%) (High ratio of tourists to residents = potential stress so +ve)	Volume of untreated waste water (Industrial + domestic + tourism) as % of total run-off (data from other sectors) : this is a proxy for load, load itself would be better but very difficult *(+ve, i.e. more volume of untreated waste water is more water stress)* (m3 / m3)

[18] The indicator team is made up of researchers specialising in the various sectors included in the ISWSI, and these suggested indicators in the Appendix have been compiled after much discussion. For the process of derivation of this Index, please see Appendix.

4.4 Potential variables for inclusion in the ISWSI

A selection of possible variables for each component and category is provided in Appendix. Table 3 above provides a suggested selection to represent water stress at a test site. For any indicator included in this table, which is not available at the test site, a replacement can be made. Where possible, selection of variables to be used should be made by the JWT and the stakeholders at the site.

4.5 Weighting index components and variables

No uniformly agreed upon methodology exists to weight the individual indicators before aggregating them into a composite index. Different weights may be assigned to each sub component in order to reflect their economic significance (collection costs, coverage, reliability and economic reason), statistical adequacy, speed of available data, etc. Weights usually have an important impact on the composite index value and on the resulting ranking. This is why weightings need to be made explicit and transparent. It is important to point out that no matter which method is used, weights are essentially value judgments and have the property to make explicit the objectives underlying the construction and use of a composite index. Commonly used methods for weighting include the following:

- **Equal weights**
- **Weights based on statistical models:**
    - Principal components analysis
    - Data envelopment analysis
    - Regression analysis
    - Unobserved components models

- **Weights based on public/expert opinion:**
    - Budget allocation
    - Public opinion
    - Analytic Hierarchy Process
    - Conjoint analysis

When weightings are obtained using public opinion, they are a valuable way of ensuring that views of different stakeholders can be included. To ensure the some means of standardised comparisons of different places, a baseline is generated by constructing the index using equal weights. In the Aquastress project, the determination of the weightings for the construction of the AWSI at the test sites will be done in consultation with stakeholders, and their application will be made clear to ensure transparency in the interpretation of the results. (ie weightings are a political issue and must be regarded as such).

For the purpose of cross site comparisons, the to be agreed core indicator set (as illustrated by Table 3), will be calculated as a base line with equal weights for all indicators, as well as with the locally determined weights to illustrate the differences weightings will make in the calculation of the composite index.

4.6 The concept of the potential margin in the AWSI

The second piece of information required to calculate the AWSI is based on the concept of the *potential margin.* It aims to represent how close the water resources system is approaching its natural endowment limits, including, where relevant, any imported water. This measure is based on the components of a simple water balance. For the purpose of the calculation of the potential margin of the AWSI, the water balance at a test site can be summarised as follows:

$$NBE + IMP = TER + EXP + RRR$$

Where:

NBE = the total *Natural Baseline Endowment*. This refers to all naturally available water resources for any site or area, which should include both renewable surface water and groundwater. It should take into account all the components of the balance which are naturally available due to the effective precipitation inside the test site area, as well as all the waters which enter naturally into the system: river discharge from upstream, groundwater flow (potentially usable), spring discharge, etc. (see Box 2 for other descriptions and terms for this concept)

IMP = *imports* (geographical movement of water to the site). This includes the water which is imported from outside the test site (diversions, desalinated water etc).

TER = *Total Exploited Resource.* It represents the water which is currently withdrawn for use (consumed or eventually given back to the system) inside the test site by human activities (domestic, industrial, agricultural). TER is the water which is actually withdrawn (diverted from spring, rivers, dams, or abstracted from aquifers) and distributed to human activities. The environmental water needs inside the test site should be included as well. This amount will depend on a 'political' decision, and it will affect ecological conditions locally; and downstream. Requirements to preserve environment downstream is included in the export (EXP) component.

EXP = *exports*. This considers the volume of water which is committed to downstream users including the environment.

RRR stands for *Residual Renewable Resource*. This is the amount of water in the test site that is left in the local system, which has not been yet consumed by local or downstream users. This amount is obtained subtracting both TER and EXP from *NBE* and IMP:

$$RRR = NBE + IMP - (TER + EXP)$$

NBE + IMP is what would be defined in Economics as supply; and TER + EXP demand.

Other definitions of the *Natural Baseline Endowment* in the literature

> Gleick (2002) reports a definition for **total natural renewable water resources**, which should include both renewable surface water and groundwater, thus representing the water made available by the natural hydrologic cycle, unconstrained by political, institutional or economic factors. Cosgrove & Rijbersman (2002) define the **renewable water resources** (also called "blue water") as the portion of rainfall that enters into streams and recharge groundwater. Sullivan et al. (2002), in order to estimate the components of the Water Poverty Index, define the **primary natural endowment** (or primary availability) as the quantity of water that is naturally available at or near the location of interest, without any human interventions. It should include also such potential resources as deep groundwater, even if currently there are no boreholes to exploit it. These definitions indicate there is a general concept of the renewable resource as the amount which arrives into an area in relation to the hydrological cycle, including both surface and groundwater.

The Potential Margin (PM) is calculated as a ratio between the RRR (as defined above) and the supply side of the water balance (NBE+IMP):

$$PM = \frac{\mathrm{RRR}}{\mathrm{NBE} + \mathrm{IMP}} \qquad o < PM < 1 \qquad [3]$$

4.7 Definition of water resources used in the calculation of the potential margin

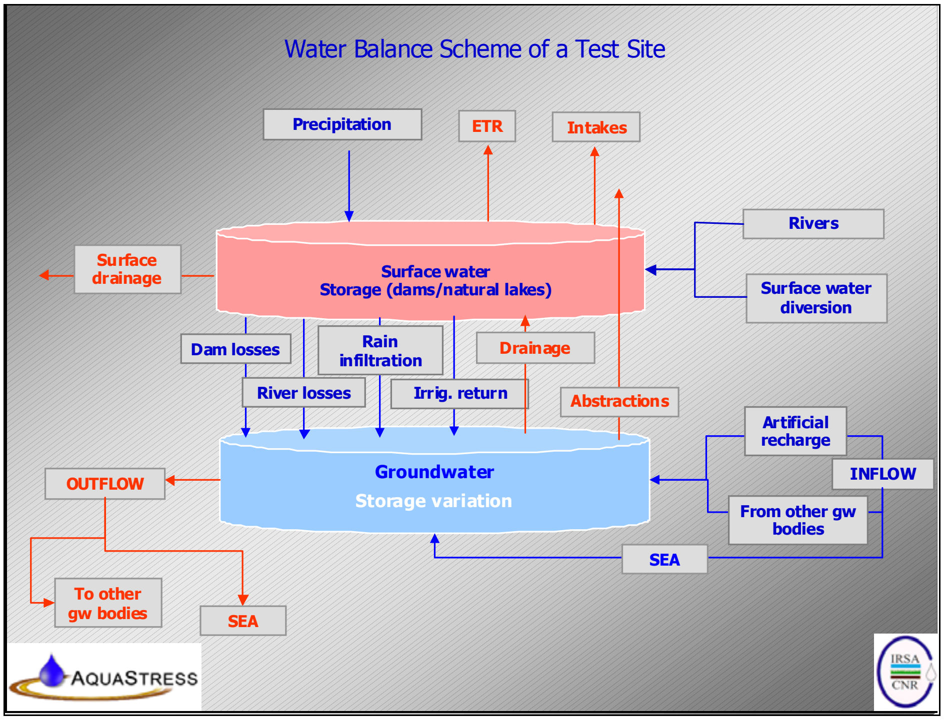
In order to be able to calculate the potential margin part of the Aquastress Water Stress Index, it is necessary to clearly define water resources. This may seem simple, but in fact can be considered and defined in various different ways. Figure 7 illustrates the conceptualisation of the water balance of a site as it is used in the determination of the potential margin, and this highlights some of the practical issues associated with the estimation of the PM for the AWSI.

- *Boundaries of the system***.** In order to perform a global evaluation of water availability at the site scale, information is needed, including not only the discharges or volumes entering and leaving the system, but also the definition of the boundaries of the system. As a general rule, the same approach which is used in hydrological and hydrogeological modelling should be adopted. Exchanges between surface waters and groundwater should be carefully estimated as they can be considered as both inputs and outputs in relation to the part of the system considered. Analogously, abstractions and intakes are not necessarily "outputs", depending on whether they are exported or recycled inside the site. In the latter case, the quality of the water after use should also be considered. It is important to stress that for sustainable development the steady state situation should be considered, because representative of the long term condition, unless important changes are foreseen in the relevant time period (e.g. climate change). Figure 10 illustrates graphically an example of water resources in a test site.
- *Surface water*. Inputs to the surface system are the effective precipitation (precipitation less evapotranspiration) in terms of volume per unit time, but also the discharge of rivers entering

the system, ground waters issuing inside the area, artificial diversions. The "outs" are the fluxes exiting from the system, also as consumed water. These can eventually go to the groundwater part of the system, hence could still be part of the available resource. The fraction of the effective precipitation entering the surface system and then recharging the aquifers is to be considered obviously only once.

- *Groundwater.* 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 a much more difficult task than in the case of a surface system.
- *Problem of double counting data from surface and groundwater.* River discharge can be partly fed by groundwater (base flow), whether they issue along the river bed (linear spring) or in a more localised way (localised spring). The proportion of groundwater vs. runoff can vary considerably, depending mainly on the hydrogeological setting, and on a seasonal scale on climate features, the base flow being in general dominant in drought periods. While counting for surface and ground water availability it is important to notice that the whole natural discharge of a river could be due to both components, hence one should be aware not to double count the same amounts.
- *Drought periods.* It seems more useful to use drought period values (or at least dry season values) where possible, in order to calibrate the estimation on critical periods rather than on average availability periods.
- *Time variability.* While accounting for the renewable resource, time variability (at seasonal and interannual time scale) 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: on the other hand river surface runoff excess could be considered as a resource only whenever it is possible to store it (e.g. in natural or artificial basins) for later use. Fritsch (2001) has suggested that several estimates of water resources, which are accurate in terms of statistical approaches and data rich, are finally biased by the use of a rough coefficient to transform total river flow into the amount which is available most of the time.

Figure 7: The water balance scheme of a test site



The upper cylinder represents the surface system, the lower one the aquifer. “Inputs” and “Outputs” are represented by blue and red arrows; exchanges between surface water and groundwater are also considered.

4.8 The formula for calculating the Aquastress Water Stress Index (AWSI)

The AWSI is obtained by combining equations [2] and [3] from above:

$$AWSI = \frac{\dfrac{w_D I_D + w_{Ag} I_{Ag} + w_I I_I + w_T I_T + w_E I_E}{w_D + w_{Ag} + w_I + w_T + w_E}}{\dfrac{RRR}{NBE + IMP}} \qquad [4]$$

$$0 < AWSI < \infty$$

Equation [4] is shown as a graph in Figure 11 below.

For each value of ISWSI (ranging between 0 and 1) a different curve is obtained.

For example

$$\text{if} \qquad ISWSI = 1 \qquad \Rightarrow \qquad AWSI = \frac{1}{\dfrac{RRR}{NBE + IMP}}$$

In this case

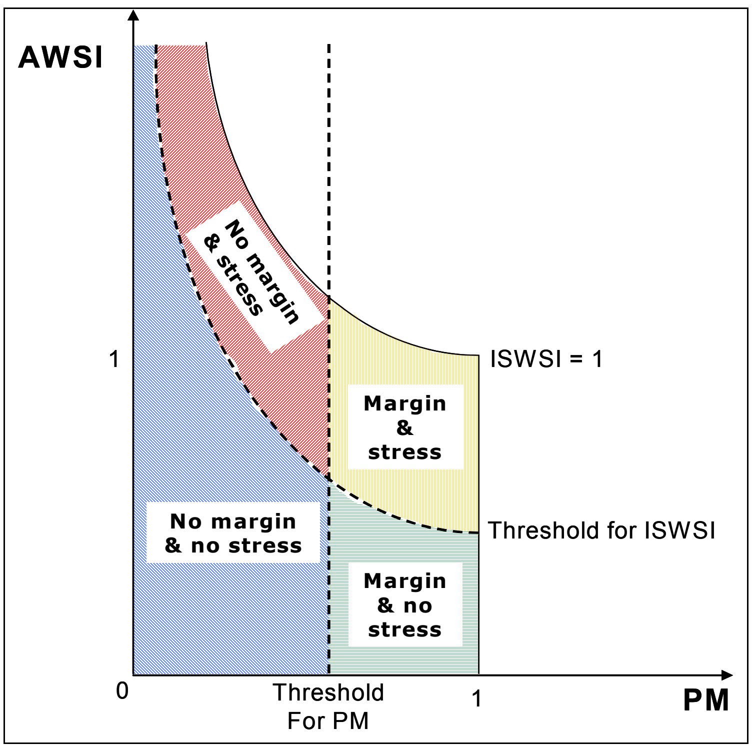
AWSI = 1, then PM = 1, and as PM reduces to zero, ASWI go to infinity.

In other words as ISWSI increases, the Aquastress Water Stress Index (AWSI) increases; and as the potential margin reduces, AWSI increases.

4.9 Graphical representation of the AWSI

A threshold for ISWSI could be set to indicate whether there is stress across the sectors; any number above this threshold would indicate current stress across the sectors (shown in Figure 8 by the area in red oblique and yellow vertical lines), and numbers below this threshold would indicate no stress (shown in Figure 8 by the area in blue oblique and green horizontal lines).

Figure 8: Graphical representation of AWSI



At the same time, a threshold can be set for the potential margin, which would define whether a site has still got a safety margin that might allow the local sectors to overcome the water stress problems. Numbers on the right of this threshold indicate that there is a safety margin (shown in Figure 8 by the area in yellow vertical and green horizontal lines). Numbers on the left of this threshold indicate that there is no water left in the system to be used to overcome local water stress (shown in Figure 8 by the area in blue and red oblique lines). The determination of these thresholds will be dependent on local consultation of experts.

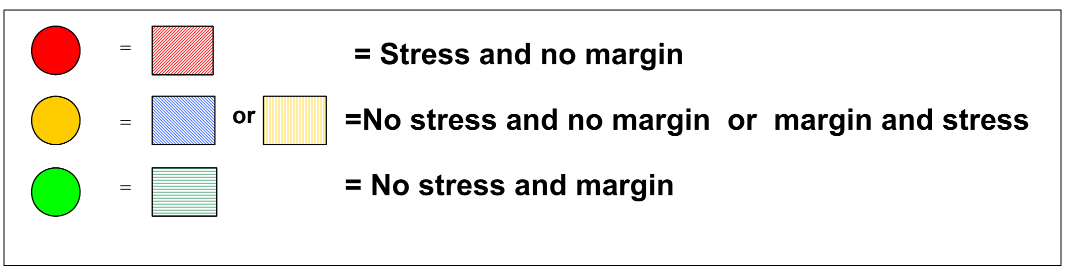
Depending on the score for ISWSI and the potential margin (PM), a case study site will be able to see in which area of the graph is falling; and draw conclusions about its level of sectoral stress and its level of resilience to this level of water stress. This will assist in water resources allocation and sectoral planning and management.

In order to facilitate ease of interpretation of the results of this analysis, a '*traffic light'* system will be used. Under this system, guidance for policy makers and water managers be based on three simple states:

- green (acceptable standard)
- orange (cause for concern) or
- red (very fragile situation)

The information displayed in Figure 9 could be used to set up the 'traffic light' system (see Figure 9). Any AWSI value falling in the '*stress and no margin'* red area could be translated in a RED traffic light; any AWSI falling in either *'no stress and no margin'* blue or '*stress and margin'* yellow area could be translated in a ORANGE traffic light; and any AWSI falling in the *'no stress and margin'* green area could be translated in a GREEN traffic light.

Figure 9: Key to translate figure 11 into the 'traffic light' system



Separating the potential margin into local potential margin and imported water

No conclusions can be drawn from equation [4] on how much of the potential margin is actually due to local water endowment and how much to imported water. A system could have a high potential margin but be heavily dependent on water from outside the system. To be able to show the level of dependency of the system to imported water, the PM equation had to be rewritten.

Starting again from the water balance equation:

$$RRR = NBE + IMP \quad (TER + EXP)$$

The imports are now subtracted from both sides of the equation, to be able to show if the total local natural baseline endowment (NBE) is enough to supply both the local and external water demand (TER and EXP respectively):

$$RRR \quad IMP = NBE \quad (TER + EXP) \qquad [6]$$

The left side of equation [6] shows the amount of local residue:

$$RRR - IMP = RRR_L$$

The local residues RRR_L can be both positive and negative in sign.

If $RRR_L > 0$ it follows that:

$$RRR > IMP \qquad NBE > TER + EXP$$

The total local natural baseline endowment (NBE) is big enough to supply both the local demand (TER) and the external demand (EXP).

if $RRR_L < 0$ it follows that:

$$RRR < IMP \qquad NBE < TER + EXP$$

The total local natural baseline endowment (NBE) is not big enough to supply both the local demand (TER) and the external demand (EXP); therefore, imports are playing an important role in the water balance. When RRR_L is negative means that there are imports of water to the site to overcome local water deficit.

The potential margin is now rewritten as:

$$PM_L = \frac{RRR_L}{NBE} \qquad -\infty < PM_L < 1$$

It is clear that the wetter is the study site, so the larger is NBE, the higher is the probability that the local potential margin (PM_L) is positive and close to 1. The drier is the area, so the smaller is NBE, the higher is the probability for PM_L to be close to 0 or even negative as in this case imports are required to compensate for the local water deficit.

ASWI has now been rewritten in two different equations ([5a] and [5b]), to ensure that as PM_L decreases to zero ASWI increase and as PM_L tends to $-\infty$ the absolute number of AWSI tends to $+\infty$. This was done to ensure that a high value for the ASWI is always an undesirable state, either because there is high external dependency (imports), or the system does not have any local potential margin.

$$\text{ASWI} = \begin{cases} \dfrac{\text{ISWSI}}{\dfrac{\text{RRR}_L}{\text{NBE}}} = \dfrac{\text{ISWSI}}{\text{PM}_L} & \text{if } \text{P}M_L > 0 \quad 0 < \text{ASWI} < \infty \quad [5a] \\[2em] \left| \dfrac{\text{ISWSI}}{\dfrac{\text{NBE}}{\text{RRR}_L}} \right| = \left| \text{ISWSI} \quad \text{PM}_L \right| & \text{if } \text{P}M_L < 0 \quad 0 < \text{ASWI} < \infty \quad [5b] \end{cases}$$

Equation [5a] represents the ASWI when the imports are not very high; the study site, in this case, is relying mainly on the local endowment.

Equation [5b] represents the ASWI when the local endowment is not enough to overcome the local and down stream water needs, and imports are brought in to overcame the local water deficit.

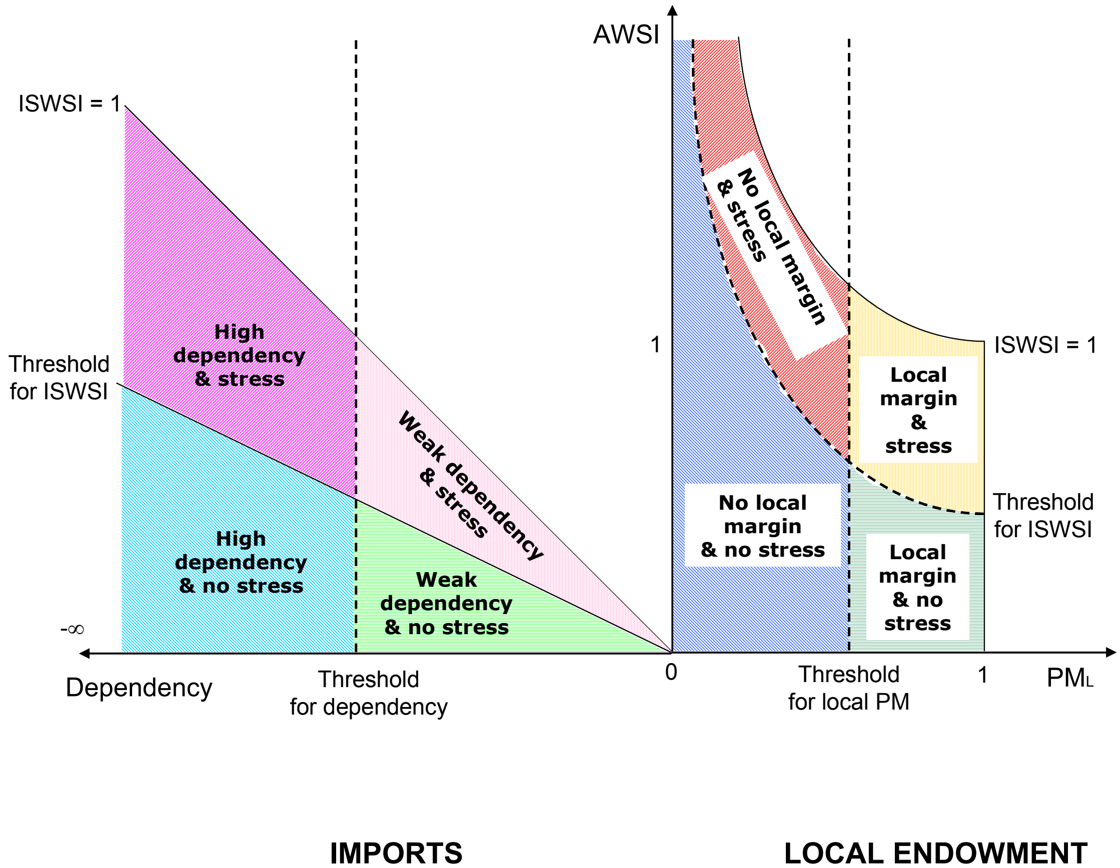
Figure 13 graphically represents both equation [5a] and [5b]. The right side of the graph represents equation [5a] and the left side the equation [5b]. The right side of the graph is similar to the graph in Figure 8, with the difference that Figure 10 represents the local potential margin and not the overall potential margin as in Figure 8.

The left side of the graph in Figure 10 shows the level of dependency of the study site to water imports. A threshold for dependency could be set to separate the situations of weak dependency from the ones of high dependency. The higher is the level of dependency to imports the more fragile is the position of the study site to possible shortage from outside the local system. If the study site has high local endowment there is lower probability that it depends on imports, in this case its AWSI will fall in the right side of the Figure 13.

The ideal situation for a test site would be to fall either in the light green horizontal line area on the left of Figure 10 or in the dark green horizontal line area on the right of Figure 10; in these areas there is either no current water stress and weak dependency or local margin and no current water stress.

PM_L

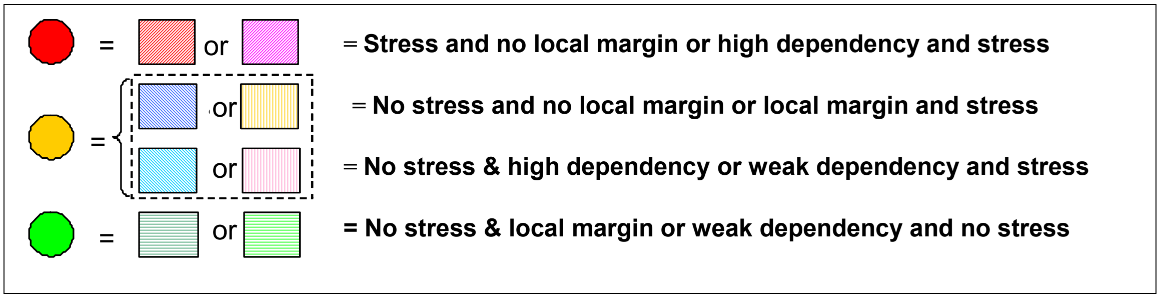
Figure 10: Graphical representation of AWSI when external dependency is also included



4.10 Interpreting the Aquastress Water Stress Index

The information displayed in Figure 10 could also be used to set up the 'traffic light' system (see Figure 11). Any AWSI value falling in the 'stress and no local margin' red area and in the 'high dependency and stress' pink area could be translated in a RED traffic light; any AWSI falling in either 'no stress and no local margin' blue area, 'stress and local margin' yellow area, 'no stress and high dependency' light blue area, or 'weak dependency and stress' light pink area could be translated in a ORANGE traffic light; and any AWSI falling in the 'no stress and local margin' green area and 'weak dependency and no stress' light green area could be translated in a GREEN traffic light.

Figure 11: Key to translate figure 13 into the ‘traffic light’ system



4.11 Use of AWSI in a cost-effectiveness framework

The AWSI can indicate the state of water stress in test sites, but to be able to determine which mitigation option to implement to reduce water stress, a cost effectiveness approach might be used. To be able to carry out a cost effectiveness analysis, it is important to be able to estimate how the AWSI would change under the different mitigation options and to know the implementation cost of each of the mitigations.

A mitigation option could affect either ISWSI or the PM or both. For example, the option to introduce desalination would affect PM, by increasing the overall water supply (in particular the import component). In this case PM would increase and consequently AWSI would decrease, which is the objective of the Aquastress project. The percentage decrease of AWSI would be then compared to the costs of having desalinated water. Given the higher costs of this option, it could be more costs effective to implement a mitigation option by reducing the demand component, which affects both ISWSI and PM. The cost of this mitigation would be then divided by the percentage change in AWSI. Comparing the cost effectiveness of each of the mitigation options, the most cost effective mitigation option could be then selected.

The cost-effective value of mitigation *i* is so calculated:

$$CE_i = \frac{Costs_i}{\frac{\Delta AWSI_i}{AWSI}}$$

The mitigation option with the lowest CE is the most cost-effective mitigation option.

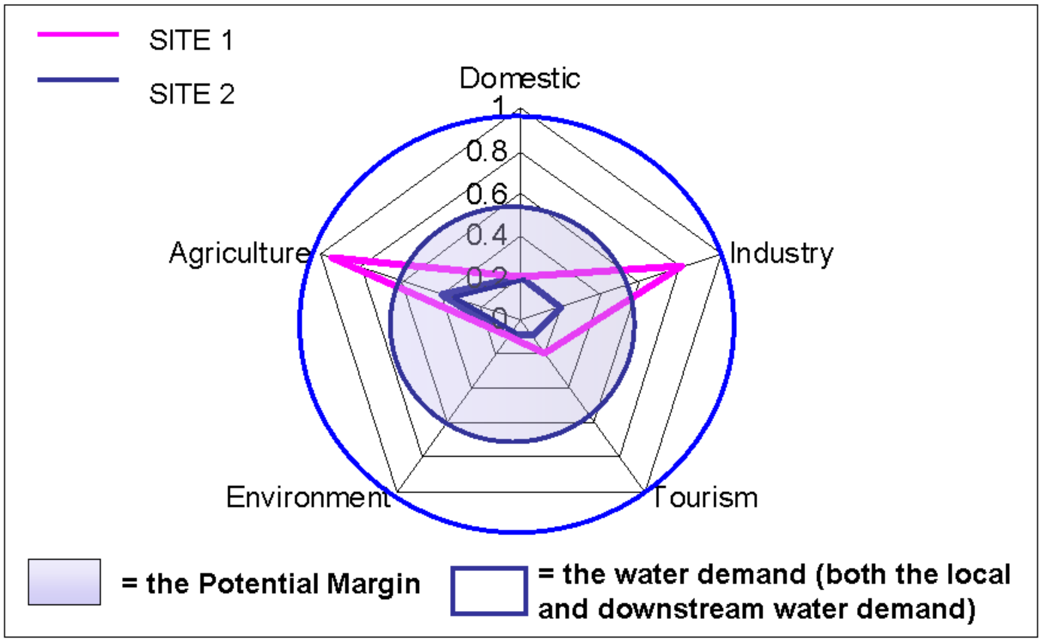
4.12 Displaying component parts of the AWSI for decision support

To be able to summarise all the information provided within the AWSI, the results are displayed in a 5 point figure. This enables easy comparison of selected ‘*hotspots’,* through simple simultaneous comparison on five major points. An illustration of this based on hypothetical data is shown in Figure 12.

Following Figure 12 shows also the level of the overall potential margin represented by the shaded blue area. The overall potential margin ranges between 1 and 0. The larger is the shaded area (i.e.

the closer is PM to 1) the better is the situation for the study site, as it indicates that the site has got a certain level of flexibility to overcome potential or current level of water stress.

Figure 12: Cross-sectoral comparison



Note: Tourism and other services have a significant impact on the water sector, (both from the demand and supply sides) but this impact is qualitatively different from that of other '*heavy*' industries, and so for this reason, these two have been separated.

5 CONCLUSIONS AND FUTURE WORK PLANS

The work carried out in WP2.1 has been successful in its goals of identifying and constructing an indicator of water stress, and identifying work that needs to be done to improve our knowledge of how this can best be done. The Aquastress Water Stress Indicator (AWSI) has been constructed after much discussion with workblock partners and the wider Aquastress team. It attempts to recognize the issues relevant to the case study sites and provide a measure by which the degree of water stress, as defined above, can be assessed. When this is complete, the information from the index is combined with other information to provide the Aquastress Water Stress Matrix (AWSM), providing a holistic and integrated tool for water resource evaluation at the study sites.

At this point in time, we are recommending that this first be used to provide a baseline value for each site, with WB 2 providing technical support for the process. When that has been achieved, case studies can decide on its further application, requiring the weightings of components to be assigned by them, to provide a specific targeted assessment, for prioritization purposes, rather than comparative ones.

5.1 Application of AWSM to support decision making

The use of integrated water resource assessment tools such as the one developed here can play an important role in the achievement of IWRM. It is hoped that within the remainder of this project, there will the opportunity to field test the methodology, and improve any weaknesses identified through its application. This will result in the generation of a robust and reliable indicator methodology which can be embedded with a suite of other information to produce the Aquastress Water Stress Matrix, which we argue will combine the best available information on which water allocation and management decisions can be made.

The process outlined here will enable users of the AWSM and AWSI at the study sites to identify the extent to which they are dependent on local or imported water sources. It will also enable them to identify the strengths and weaknesses of the water management situation in their location, with a view to further identifying causes of water stress. When coupled with a cost effectiveness analysis, and with stakeholder consultation, appropriate responses to these causes can be identified.

5.2 Further development of the AWSM

As part of the indicator development process, an expert workshop is to be held in November 2007. At this workshop, international and local experts and end users will have the opportunity to contribute to the review and final structure of the AWSM and AWSI. It is important to remember that these two are linked, and that detailed work to calculate the AWSI from local data from the site locations will be complemented by the addition of other relevant data in the framework of the AWSM.

When the Aquastress Water Stress Index (AWSI) and the Aquastress Water Stress Matrix (AWSM) have been produced at the study sites, the information will be evaluated by a range of stakeholders with a view to improving the model if required. If resources permit, there may be the opportunity to make refinements as needed, as identified in this process. The lessons learned from the indicator development activities will be collated and produced as part of the final report for the Aquastress project.

Acknowlegements.

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APPENDIX

A. TECHNIQUES OF CREATING INDICES

1. Definition and classification of indicators and indices

Indicators provide a convenient method of summarising large amounts of data into a single value, which can then be compared over time or between countries and regions to reveal changes and differences. They also provide a means of communicating information about progress towards a goal (such as sustainable resource management) in a significant and simplified manner.

The challenge of a good indicator is to be able to create an index or an alternative form of representation, which is characteristic of a whole country or region using a relatively small sample. "*Indicators must simplify without distorting the underlying truth (and) reduce the complexities of the world to a simple and unambiguous message*" [19] Thorough design of the index is therefore essential in order to ensure that it achieves this accurately. Each variable or representative indicator has been carefully considered on the basis of its relevance, its representativeness, data availability and its ease of computation. This has been an important consideration throughout the indicator development activities in the Aquastress project.

2. The use of indices for policy dialogue

The use of indices as policy tools began in the 1920s (Fisher, 1922; Edgeworth, 1925. This work defined an index number as a measure of a quantity relative to a base period. Indices are a statistical concept, providing an indirect way of measuring a given quantity or state, effectively a measure which allows for comparison of different aspects of water management issues, over time. Key issues which have to be addressed in the construction of any index are:

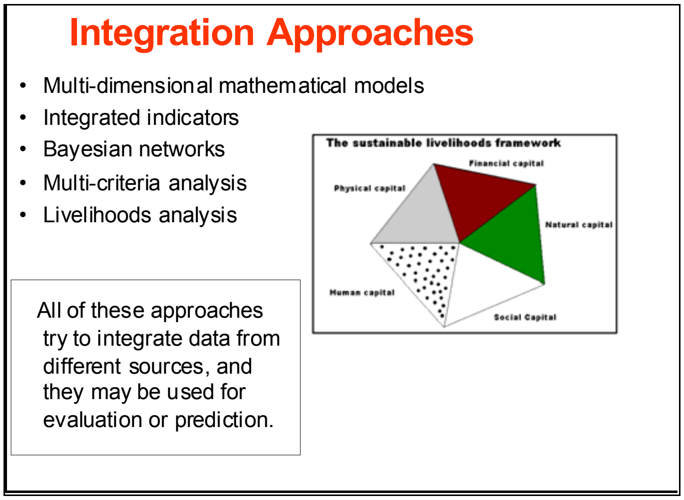
- choice of components
- sources of data
- choice of formula
- choice of base period (in this case, this will be the first year of calculation)

Apart from these empirical issues, the main point of an index is to quantify something which cannot be measured directly (e.g. how water stressed a community or region is) and to measure changes (e.g. the impacts of economic growth on water use over time). The proposed Aquastress Water Stress Index (AWSI) fits this concept of an index by being made up of defined components which, combined together, indirectly measure water stress, since it is too complex a concept to be measured simply on a hydrological scale.

Other ways of integrating data from several disciplines to understand complex problems are shown in Figure 13. This illustrates the different types of approaches that can be taken. In this Work Package of the Aquastress project, (WP2.1), the work has been to investigate the indicator approach, so this has specifically been the focus of investigations.

[19] World Health Organisation: Environmental Health Indicators.

Figure 13: Water indicators displayed through GIS



Source: Sullivan, 2005. Presentation to Aquastress Porto workshop

There is a considerable literature on the use of indicators (Anderson, 1991,DoE, 1996, Hammond et al, 1995, Rennings and Wiggering, 1997 Rogers et al., 1997, Salameh, 2000, Streeten, 1996, World Bank, 1996, 1997, 1998), and while there may be disagreement about some of the methodological issues, it is now widely recognized that integrated indices are useful tools for policy making. As a way of addressing the more contentious issues in indicator use and development, the International Institute for Sustainable Development (IISD) organized a workshop on The Science and Policy Dialogue on Designing Effective Indicators for Sustainable Development In 1999. The Dialogue brought together 40 participants from different geographical regions and backgrounds, including policy-makers, experts on various types of indicators, academics, and representatives from multilateral organizations and businesses. This workshop began a process by which indices have become increasingly important, seen as underpinning tools to support the objectives of the United Nations Commission on Sustainable Development, and Agenda 21. Highlighting the need to be able to track trends over time, and to provide early warning signals if things are going wrong, this commission laid the groundwork for the widespread acceptance of the use of indicators for more effective natural resource management. Eventually, this became the foundation of the target indicators for the Millennium Development Goals (see Table 4)

Table 4: The Millennium Development Goals Target Indicators relevant to water stress

Goal	Target	Indicators
1: Eradicate extreme poverty and hunger.	1: Halve, between 1990 and 2015, the proportion of people whose income is less than one dollar a day.	1. Proportion of population below $1 (PPP) per day. 2. Poverty gap ratio [incidence x depth of poverty]. 3. Share of poorest quintile in national consumption.

Goal	Target	Indicators
	2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger.	4. Prevalence of underweight children under five years of age. 5. Proportion of population below minimum level of dietary energy consumption.
7: Ensure environmental sustainability.	9: Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources.	25. Proportion of land area covered by forest. 26. Ratio of area protected to maintain biological diversity to surface area. 27. Energy use (kg oil equivalent) per $1 GDP (PPP). 28. Carbon dioxide emissions (per capita) and consumption of ozone-depleting CFCs (ODP tons). 29. Proportion of population using solid fuels.
	10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation.	30. Proportion of population with sustainable access to an improved water source, urban and rural.
	11: By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers.	31. Proportion of population with access to improved sanitation, urban and rural. 32. Proportion of households with access to secure tenure (owned or rented).

The challenge presented by the Millenium Development Goals demonstrates the need for prioritization in water planning and management. It is essential that the financial and human resources devoted to meeting these goals are allocated efficiently, in such a way as to assist the most needy communities, and get maximum benefit from our investments (Sullivan 2003). An essential component in the achievement of this goal is the effective implementation of IWRM.

While single indicators can provide certain information for key issues or sectors, the achievement of IWRM requires that information be integrated both spatially and where possible, temporally, to assist in the complex decisions associated with whole basin-scale river management. During the Johannesburg World Summit on Sustainable Development in 2002, countries pledged to develop integrated water resource management and water efficiency plans by 2005, with support to developing countries. While this suggests a clear recognition of the importance of governance in the water sector, a recent assessment of country status regarding IWRM plans revealed that many countries still have a long way to go when it comes to formulating new IWRM plans as set out in the Johannesburg Plan of Implementation, 2002. The development of an effective integrated tool to asess progress in the water sector will be of use in the formulation and operationalisation of such IWRM plans, and it is with this broader goal in mind that the work reported here has been carried out. This means that not only will the tool be of use to the case study sites, but it will also potentially have much more wide reaching applications for water management in general. Through the combination of the sectoral stress indices with the measure of water avialability (in the form of the Potential Margin), it becomes possible to examine the current state of the water resouce, and the impact of any change. By then combining this information into the Matrix, with that from other sources, this becomes a complex tool reflecting a complex and dynamic system.

3. Classification of indicators

There is a huge literature on indicators, and a number of ways of classifying them, usually depending on their specific focus. In this section we briefly present some of the main issues.

Usually, indicator-sets are based on a specific conceptual framework, which defines the basic assumptions of the assessment, e.g. what are the issues of concern, from which perspective the assessment will be done and how sustainability is understood. These conceptual frameworks are supposed to ensure the comprehensiveness or at least the consistency of the selected indicator set. Each conceptual framework establishes a unique approach of assessing information about the system under consideration (Besleme and Mullin, 1997:43). MacLaren (1996) provides a comprehensive overview on different conceptual frameworks of indicator development and use. She distinguishes 5 different frameworks, namely:

- **domain-based:** This framework starts with defining the key dimensions of sustainability and identifies indicators for each of them. According to MacLaren it is most effective in covering all dimensions of sustainability, but fails in linking the indicators with sustainability goals.
- **goal-based:** This framework starts with the identification of the sustainability goals and creates one or more indicators for each goal or goal combination. One weakness of this approach is that it has difficulties in capturing complex interrelations among the various dimensions of sustainable development, as it is still a fairly simple indicator approach.
- **sectoral:** Within this approach indicators are developed for each sector for which the administration has typically responsibilities. Therefore the actual coverage of sectors depends on the political scale the indicator set is aimed for. It is suited to assessments of policy performance, but is not very effective in indicating linkages across different sectors.
- **issue-based:** This framework starts with identifying and listing of key issues of sustainability in the system of concern, e.g. air quality, water resources, employment. To theses key issues one or more indicators are linked. Like the sectoral framework the issue-based framework is rather context specific as the key issues many differ among assessment contexts.
- **causal:** This framework goes beyond the above one by considering cause and effect relationships. Human activities are seen as affecting environmental conditions as stressors, which in turn has impacts to health, economy, and social conditions. To these impacts policy is responding due to alleviation of the stressor or modifying the environmental conditions directly. Within the framework

indicators will be developed for the stressor, conditions and the policy responses. However the distinctions between the different cause-effect-relations are not always clear.

The most commonly used conceptual frameworks in sustainability assessments are the domain-based and causal frameworks, often applied in combination. Within the ecological dimension of sustainability the OECD (1993) has developed the Pressure-State-Response framework which groups the information about the underlying system in three interdependent categories. The first category pressure -indicators gives information about man-made environmental stress. The state indicators aim at informing about environmental quality and last the response indicator category indicates how and to which extent the society react to environmental changes. This causal framework within the ecological dimension of sustainability was enhanced in 1996 by the UN-Commission on Sustainable Development (CSD) and the UN Statistics Division (UNSTAT) with the Driving Force - State - Response (DSR) framework. This framework was developed together with a catalogue of 134 indicators for all three dimensions of sustainable development. This framework again has been enhanced by the EEA with the pressure-category and an impact-category to the Driving Force - Pressure - State - Impact - Response (DPSIR) framework considering all human activities (processes and archetypes) with negative and positive impacts to sustainability. Based on these three frameworks, most approaches to indicator-sets have been developed, however, most often indicator sets for sustainability assessment focus either on the ecological dimension or on combinations of ecological and economic indicators. The indicator set of CSD and UNSTAT should be the reference set for the national reporting about progress towards sustainability, asked by the CSD (UNCSD, 1999). Hence, the approach has been adopted as well by Eurostat, the European Commission and the EEA for their own indicator-sets (European Commission and Eurostat, 2001).

A second classification of indicator-sets is according to their complexity and the aggregation level. In general, existing indicator-set approaches can be grouped on an analytical level into two different classes:

List of indicators

A list of indicators consists of series of measures that do not stay explicitly in a relation to each other. The single measure can be, but not necessarily, observed and displayed directly on a scale. It is the most widespread approach to capture and measure sustainability in numbers. A series of lists of indicators have been developed by different governmental and non-governmental institutions. These lists are more or less detailed and differ in its geographical and/or temporal scale or thematic approach. Some approaches use one list for each of the three dimensions of sustainability, others link indicators for all three dimensions to only one list.

Examples of lists of indicators are the OECD Environmental Indicators (OECD, 1993), the CSD Indicators of Sustainable Development (UNCSD, 1999), but also the European Environmental Indicators and the majority of Local Agenda 21 Indicator-sets.

Indices

A second class according to aggregation are indices, usually based on a combination of indicators. In comparison to a list of indicators, however, indices aggregate the rather complex information of the underlying list into a single value to improve communication and quick reference. This implies a selection, appraisal and weighting of the underlying indicators. For this procedure, however, is rather subjective as a clear and objective basis is not existing (Landis and Sawicki, 1998) and the single variable cannot be observed and displayed directly. Furthermore, indices reflect a particular perception of and theory about reality (society and nature) and value judgement about what is important (Innes and Booher, 2000: 176). Hence, by reducing complexity through aggregation, a loss in information about the underlying system and on transparency occurs as well. This however may be a means of making the complexity of information more manageable for users.

Aggregation also requires a common denominator or unit. This is normally a dimensionless value between 0 and 1, a percentage figure of change, a monetary or currency unit or physical value like land-use or resources use. The selection of the denominator, however, influences as well the selection and weighting process of the variables. Aggregated measures, like indices, often only have little meaning to the potential users of the indicator set and there is agreement that it is not possible to define only one single index of sustainable development; rather, a substantial number of indicators are needed to capture all complex and important aspects of sustainability. Moreover, Impact Assessment indicator-sets have to reflect the complexity of interactions of natural and human systems (Bossel, 2001)

Other authors have categorised indicators required for the purposes of the Aquastress Project under three broad types[20]:

- Type I - Indicators of Water Stress.
- Type II - Indicators of Water Stress Perception.
- Type III - Indicators of Performance for the different mitigation options.

Type I indicators, corresponding to the characterization process, are objectively quantifiable (e.g. precipitation measured in mm, renewable groundwater resources etc).

Type II indicators correspond to the users perception analysis, and are subjective, because their values to users will depend on the conflicts and the allocation rules/priorities that exist in any given region[21].

Type III indicators in general can be measured by the improvement in the Type II and I indicators following the application of a mitigation option, and should lead to the acceptance of that option by the Local Stakeholders, decision makers and planners.

There are many issues relating to water management which cannot be captured in a conventional quantitative manner. Capturing the role of institutions, and other water governance issues is a challenging task, and it is important to recognise that these cannot always be represented numerically. Various action research methods can be used to elicit the kind of information which is needed to reflect the role played in water management and decision-making by the various economic agents involved. This therefore requires that the analytical technique used to develop a

[20] This section has been supported by a contribution from D.Assimacopoulos

[21] Type I Indicators can be found in the literature, such as those proposed by UNESCO (The United Nations World Water Department Report, 2003, Water for People, Water for life Unesco Publishing), Plan Bleu (Les Indicateurs d' economie de l' eau ressources et utilisations, Plan d' Action pour la Mediterranee, Plan Bleu, May 1996).

holistic measure for water management will need to take account of both quantitative and qualitative data.

4. Creating maps from indicator data

Mapping data from indices can be very useful in displaying spatial variability in indicator output. Census data provides much data, and may allow a fine resolution map to be created, but unfortunately, information is often out of date. Bottom-up approaches to data collection and index creation have the advantage of allowing participants to introduce their own criteria, but lack of structured questions can make it hard to extrapolate results and compare information. Household surveys can to some extent provide a basis for resource mapping, and indicator maps constructed using GIS can deliver clear information on the spatial distribution of water conditions. GIS makes it easier to integrate data from various sources and disciplines, which, if a conventional index approach had been used, may have been harder.

Using a map rather than figures has distinct advantages when it comes to developing countries, as they are more easily understandable to a wider audience. Mapping therefore provides a powerful tool for decision makers. Additionally, mapping allows the limits of analysis to be expanded to include ecological factors and allow new variables to be included. Mapping can help provide new insights into the causes of poverty that could not be found by conducting a household survey alone. Identifying physical isolation is one example. Mapping also has the advantage that it can be applied at the national and sub-national level. High-resolution maps can be used to support efforts to localise decision-making.

5. Proxy variables and social factors in indices

When considering a social dimension such as poverty, Henninger (1998) has illustrated that proxy variables can be used to capture complexities of causal factors. He points out that such indicators can be grouped into three major dimensions of economic, social and enabling environment. Under the economic dimension, either current consumption expenditures, income or wealth can be used. Social aspects of well-being can include measures of nutrition, energy, sanitation and water availability, family planning or education. Such indicators have the advantage that they can be used as a proxy for the constraints of human welfare but have the problem that they can be hard to aggregate. Although less used at present, enabling environment indicators can provide important information. These can include level of empowerment, governance, participation and transparency of the legal system.

6. Internationally used method for producing indices and index based maps

The United Nations[22] (1995) use Multiple Indicator Cluster Surveys (MICS) as a method of producing indicators about the population when other data such as census data or sample survey data is not available. MICS involve surveying groups or clusters of households within the population to produce a nationally or sub-nationally representative picture. A number of problems can occur with MICS. Large and small communities may have an equal chance of being selected when in fact the larger community should have more chance. A technique called Probability

[22] UNICEF (1995)

Proportional to Size can be used to overcome this. Similarly, key groups with special needs may happen to be excluded from the survey as a result of randomness. This can be overcome by stratified sampling. Due to clustering, not all households are selected independently of each other and may therefore have similarities. This is known as design effect and can be overcome by increasing the sample size. The effectiveness of MICS was later evaluated by UNICEF (1997) who concluded that, additional training and technical assistance was required, lack of language skills were a problem and that further capacity building within countries is required.

Good survey design is essential to ensure that the correct data is collected and that questions are unambiguous. As part of this design it is necessary to ensure that the interviewers are trained to a high standard so that all interviewers conduct the survey in the same way. Pre-test questionnaires should always be carried prior to the main survey. This can highlight a number of problems such as if respondents are willing to answer questions in the form they are presented, whether questions are misinterpreted and whether or not the questionnaire has been effectively translated. This can also give an indication about the time it will take to carry out the survey and any additions that may need to be made to the questionnaire.

7. Criteria for good indicators

The World Health Organisation (WHO)[23] recognises that environmental health indicators must satisfy a number of different criteria to be effective. They must provide a meaningful summary of the conditions for non-experts as well as being testable and scientifically sound. Indicators need to be sensitive to real changes but also must not be affected by noise to any great extent. When these criteria are added to the need for cost effectiveness, the types of indicator that can be developed are limited to a certain extent. One of the greatest conflicts is balancing the need for current, high resolution data with the cost of collecting. Furthermore, different indicators demand different qualities from data, data is therefore often not interchangeable. It is also vital to ensure that indicators do not stand still, they must be adapted over time to reflect the changes that are happening in the world.

Many global organizations are involved in collecting and collating indicators. The World Resources Institute (2001) identified problems when developing indicators to assess the extent of risk to health that people face from environmental threats. National level data is often lacking or incomplete which necessitates the use of less accurate proxy measures. Similarly, Gustavson et al. (1999) find that the poor quality, inaccessibility and irrelevance of existing data are pervasive constraints to reliable indicator modelling. Greater focus is therefore required on modelling frameworks that can use incomplete data sets or qualitative information, and linking this to existing quantitative models.

Elbers, Lanjouw and Lanjouw (2000) attempt to reconcile these problems with data by exploiting the beneficial attributes of two different types of data. They combine the detailed information about living standards available from small household surveys with the comprehensive coverage of census data. Elbers, Lanjouw and Lanjouw show that by combining the strengths of each of the above, the estimator of welfare that they are constructing, can be used at a disaggregated level.

[23] World Health Organisation: Environmental Health Indicators:

This approach leads to a result that can be clearly interpreted and can be expanded in a consistent way to any measure.

Hentschel and Lanjouw (1998) investigate the use of total consumption as a household-level welfare indicator. This method has often been criticised, as it does not take into account the differing access to, and cost of publicly provided services. Hentschel and Lanjouw discuss how adjustments can be made to this indicator to take these factors into account. Careful analysis and correction of markets for basic services must be undertaken when deriving welfare measures due to some markets being highly subsidised. Meaningful values can be obtained if this is carried out. Degreene (1994) points out that many economic indicators have lost their predictive capability and that most social indicators are collected outside of a theoretical framework. Instead, Degreene argues that ecological and large scale natural environment indicators can provide more immediately powerful and convincing evidence of instability and structural change.

Data availability is always an issue when determining any integrated index. While considerable data may be available for some places, others are poorly served. In the Aquastress project, we are planning as far as possible to use specific local data relevant to the case study sites, for the purpose of applying the methodology to a variety of locations. Not only will this be of interest to stakeholders in the case study sites themselves, but the lessons to be learnt from the process will provide insights into how the methodology can be improved in future iterations.

At the global level, appropriate data for national level application can be found from many sources, and some of these may be relevant to the case study sites. These could include the following:

At the global level, appropriate data for national level application can be found from many sources, and some of these may be relevant to the case study sites. These could include the following:

- IUCN commission on ecosystem management – aquatic ecosystem health (catchment scale) http://www.iucn.org/themes/cem/ourwork/ecindicators/index.html
- OECD Statistics office http://www.oecd.org/statsportal/
- UNDP – Social dimensions of adjustment, household surveys. http://www.undp.org/
- Human Development Report http://hdr.undp.org/statistics/indices/
- EARTH TRENDS http://earthtrends.wri.org/
- UNESCO World Water Assessment Programme http://www.unesco.org/water/wwap
- UNESCO Water Portal http://www.unesco.org/water/ http://www.unesco.org/water/wwap/facts_figures/mdgs.shtml
- WHO/Joint Monitoring Programme http://www.wssinfo.org/en/welcome.html
- UNEP GEMSWATER http://www.gemswater.org
- EMWIS is the Euro-Mediterranean Information System on the know-how in the Water sector http://www.emwis.org/
- MEDRC Middle East Desalination Research Centre http://www.medrc.org/
- WMO World Meteorological Information http://www.wmo.ch/index-en.html

While this list is not exhaustive, it does demonstrate the fact that considerable data relevant to water management has been collected, but of course, it must be recognized that data sets are not perfect. Gaps exist, and there are qualitative aspects that perhaps should be included, including measures of social adaptive capacity, ethical aspects, and levels of expectations on water quality, among others. The datasets listed above also often report national values rather than data at a smaller scale, and this can be problematic if analysis is being carried out at the basin scale rather than at the national scale. Clearly, basins can be both larger than and smaller than some countries that they include.

In cases where it is not possible to acquire measurable quantities (ie. data) from which the indicator can be extracted directly, another approach is possible. This is based on data from household surveys, For instance, if the quality of water related to the incidence of diarrhoeal diseases is to be one of the indicators, this can be done approximated by asking the households to rank the quality of water as very poor, poor, medium, good, or very good and then giving the answers points from 1 to 5. This gives an approximate numerical score to the question, which can then be turned into the range 0-100, as above.

8. Conventional approaches to asses water stress

Water stress occurs when there is a greater demand for water than there is a supply of it. To understand how stress occurs, it is thus important to know how much water is available for management. To address this, there have been a number of attempts to provide a generic method to assess water resources, and a selection of these are outlined below:

The Comprehensive Assessment of the Freshwater Resources of the World (The Stockholm Environment Institute, 1997)

The first attempt to make a global assessment of water resources was the Comprehensive Assessment of the Freshwater Resources of the World (UN, 1997, Shiklomanov et al., 1997). The key concept in this approach is the assessment of total water resources at the country level in terms of the mean annual runoff for each. The runoff values were based on observed data from river flow measurement stations, supplemented by estimates based on meteorological data where river flow observations were lacking. The country values also include estimates of the water imported from or exported to other countries. Based on this assessment, country estimates of water resources and water stress expressed in terms of gross annual water resources per head of population are widely quoted. The essential point about these results is that the comparison of resources to demands is made only at the country level, and very little weight is put on the important issues such as spatial (at which scale level should one go? To assess it at country level is to include spatial variability, but just not at a fine resolution) and temporal variability. More recently, attempts are being made under the CGIAR Challenge Programme, to update this work.

Global water assessments

Some attempts address the issue of spatial and temporal variability have been made, and one example of such work is the DFID funded **GWAVA project** (Meigh et al.,1998). In this work, the use of a grid approach has provided the means whereby physical assessments of water availability are adjusted to take some account of human factors. A number of other water assessments have also been made following the grid approach. Two of these will be discussed briefly in order to illustrate what has been achieved. Arnell and King (1998) used a 0.5 by 0.5 degree grid model to estimate global runoff. This approach is similar to the GWAVA work, except that only the local runoff within each grid cell is calculated, and key aspects of water resources systems such as cell linkages, abstractions, reservoirs, lakes and wetlands are not considered.

The grid cell results are aggregated to the country level, and the comparison of resources to demands is then carried out only at the country level.

A similar, but more sophisticated approach was taken in the **WaterGAP** model (Alcamo et al., 1997). This also uses the 0.5 degree grid size, and the grid cells are grouped into 1162 catchments, giving almost total global coverage. Calculations are done at the grid level but the results are aggregated to the catchment and country scale. As before, many of the key aspects of water resources systems are overlooked, but time variability is considered as the water availability is computed for average conditions and for 10-percentile dry years

There are many other examples of these types of approaches being applied both at the global or regional scale (Vörösmarty, 2002, Gash et al., 1999), and at the national scale, for example in South Africa (Schulze, 2000). The inclusion of this brief description of water resources assessment models is important to provide the reader with some insight into how the Aquastress Water Stress Matrix takes water resources assessment forward. Through the composite index, (AWSI), resources and related attributes can be quantified, while the other contents of the matrix (the AWSM) add depth and breadth to this information for the benefit of the decision-maker, and to provide an insight into the diverse issues that must be addressed under the process of implementation of Integrated Water Resources Management (IWRM) .

B. EXISTING WATER INDICES

The use of indicators in water management has become an important issue in recent years. In particular, legislation such as the implementation of the EU Water Framework Directive (WFD) has given prominence to indicators as management tools in the water sector. In addition to the indicators of the WFD, there are many other water indicators in use today. Most of these are single indicators of water quality, which for a long time has been the area of water research most utilising indicators. There are hundreds of different indicators in use, but some of the more simple ones have been used widely as measures of specific types of water stress. These are shown in Table 5.

Table 5: Selected water indicators in widespread use

Sector	Issue	Parameter examined
Domestic	potable water quality	Coliforms, heavy metals
Domestic	domestic wastewater effluent & surface/ground water quality	Nitrogen, BOD
Agriculture	water quality	nitrates, phosphorus, land use
Ecosystem health	water quantity	ratio of groundwater abstraction to groundwater recharge
Ecosystem health	water quantity	flow regime change, water table variations
Ecosystem health	system integrity	(Estuarine / Ecosystem) Biotic Integrity index
Ecosystem health	system integrity	artificial "channelization"
Industry	salinity	EC
Industry	eutrophication	phosphorous load per l waste water
Industry	pollution	heavy metals per l waste water
Industry	demand	m3/month
Industry	outflow	m3/month

Some indicators have been combined as measures of various dimensions of water stress, including the widely used indicators relating the quantity of water available to the amount needed for certain activities. Two well known ones are:

- **Water availability per capita per year** This defines specific thresholds relating to water shortages : 1700 m3/capita/year or less: water stress, 1000 m3/capita/year or less : water scarcity
- **Water withdrawals as a share of annually internally renewable water resources** this indicates the degree of stress in a location, but does not take account of water transferred from transboundary rivers or international interbasin transfers

When individual indicators are combined together, they are referred to as an index. Many of these have been developed to address some specific issue associated with water management, as shown in Table 6.

Table 6: Selected indices related to water

Index	Variables analyzed	Application
Kincer's Index	30 or more consecutive days with less than 6.35 mm of precipitation in 24h	seasonal distribution maps
Surface Water Supply Index	snowpack, reservoir storage, streamflow and precipitation	
Marcovitch's Index	Temperature and precipitation	climatic requirements of the bean beetle
Blumenstock's Index	Number of days with less than 2.54 mm precipitation in 48h	short-term drought
Antecedent Precipitation Index	Precipitation	Reverse used for flood forecasting
Moisture Adequacy Index	Precipitation and soil moisture	agricultural drought
Palmer's Index	Precipitation and temperature in a water balance model	comparison of meteorological and agricultural drought in space and time
Crop Moisture Index	Precipitation and temperature analyzed in a water balance model	agricultural drought
Munger's Index	Length of period without 24h precipitation of 1.27 mm	daily measure of comparative forest fire risk
Keetch-Byram Drought Index	Percipitation and soil moisture in a water budget model	fire control management
Standardized Precipitation Index	Precipitation	statistical comparisons

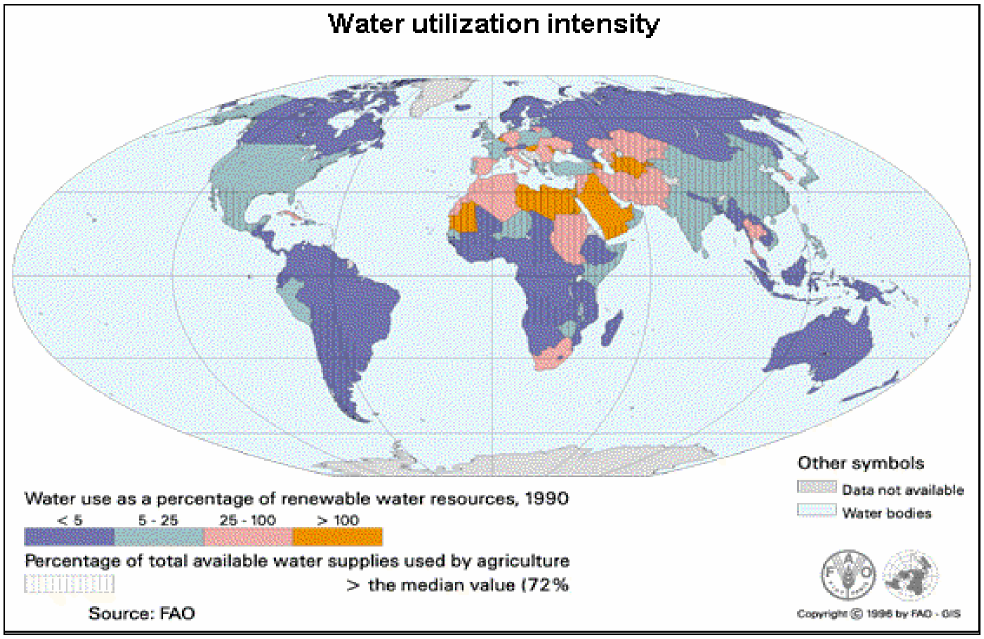
The Collaborative Council for Water and Sanitations Basic Water Requirement

The Collaborative Council for Water and Sanitation (Chattergee et al. 1999) have identified the basic water, sanitation and hygiene requirement as the minimum requirement to meet these basic human needs is calculated at 40 litres per capita, per day. This is often taken as a guide for water resource planning, but Gleick (2002) has suggested that it may be more realistic to use 20litres per day as a guide in most parts of the world. It is certainly true that in many parts of Africa, for example, the average per capita consumption is much less than 20 litres per day (Sullivan et al., 2002)

Water Utilisation intensity

The concept of water utilisation intensity has been used to identify areas which are likely to be water stressed in the future. Figure 1 shows the global distribution of WUI values. When this figure is over 100%, this means that aquifers are depleting faster than the recharge rate, or that pollution may be making some otherwise renewable supplies, unusable. In either case, water becomes a constraint on production, and more efficient means of using it becomes a vital issue. The global distribution of countries where the water utilisation intensity is over 100% is shown in Figure 14, highlighting the fact that even in 1990, some countries already faced scarcity problems, and by 2025, this number is certainly likely to increase

Figure 14: Water utilisation intensity links water availability with demand for water

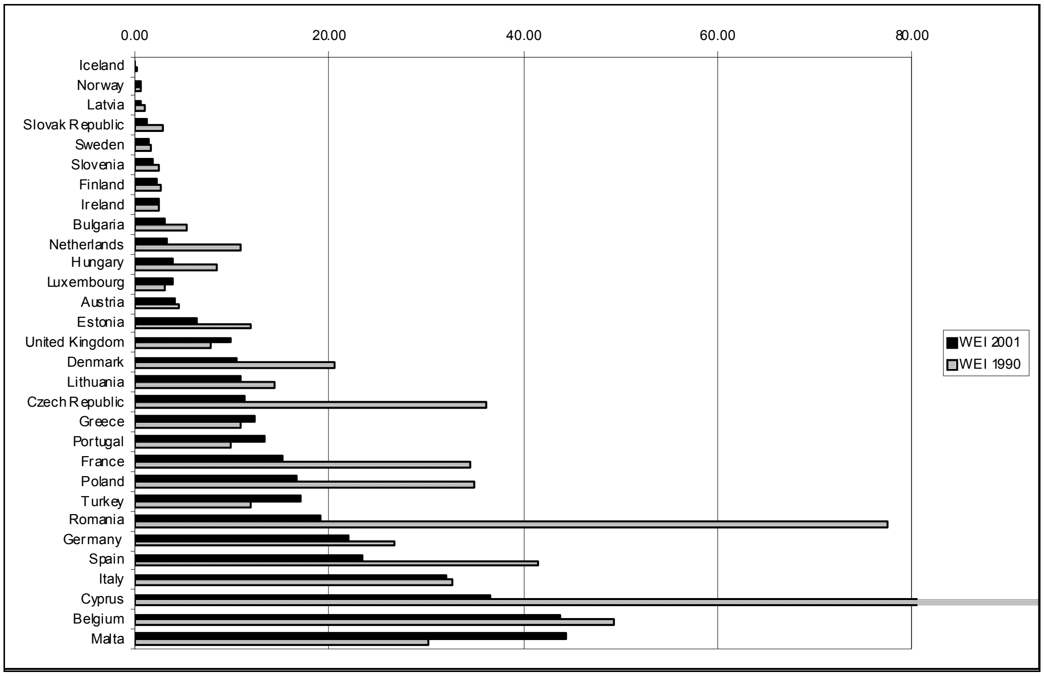


The Water Exploitation Index (WEI)

A further approach which has been applied to domestic water provision is the Water Exploitation Index (WEI), or withdrawal-to-availability ratio this compares water use with available water resources, and is derived from the mean annual total demand for fresh water divided by the long-term average freshwater availability. The freshwater resources are derived from the mean annual precipitation minus the mean annual evapo-transpiration plus the mean annual inflows to each country (EEA, 2003). The WEI can identify whether the rates of abstraction in countries are increasing over the long-term. The warning threshold is 20 %, which distinguishes a non-stressed region from a stressed region (Raskin et al, 1997). Severe water stress can occur where the WEI exceeds 40 %, indicating strong competition for water but does not necessarily result in frequent water crises. Some experts argue that 40 % is too low a threshold, and that water resources can be used much more intensely, up to a 60% threshold (EEA, 2003). Others argue that freshwater ecosystems cannot remain healthy if the waters in a river basin are abstracted as intensely as indicated by a WEI in excess of 40 % (Alcamo et al., 2000).

Figure 15 illustrates how WEI values can be used to compare changing withdrawal ratios over time. In Europe there are six countries that could be considered as having been water stressed between 1990-2001 on the WEI measure, (Germany, Spain, Italy, Cyprus, Belgium, and Malta), representing 35 % of Europes population. The four former countries have a WEI between 20 and 40 %, and the two latter have a WEI around 45 % (EEA, 2004).While this is a useful measure, it does rely heavily on annual average values, and also takes no account of infrastructure or institutional arrangements which clearly impact on water use rates.

Figure 15: Water Exploitation Index (%) across Europe 1990-2001 (EEA, 2004)



The Social Water Stress Index

Work by Leif Ohlsson in Sweden attempted to link the physical assessments of water with relevant social factors to create a more holistic approach (Ohlsson, 1998). In this model, the physical measure is provided by the assessment of available renewable water, and this is linked to adaptive capacity through the use of the UNDP Human Development Index to create what he refers to as the Social Water Stress/Scarcity Index. In the process of the development of the Water Poverty Index (WPI, see below), work provided a strong starting point, and Dr. Ohlsson was consulted on the usefulness of the tool. It is argued that the WPI takes this work further, as it also explicitly takes account of both water productivity and environmental impact, this making it a more holistic tool.

The Water Poverty Index (WPI)

This is a composite index designed to link water availability and human welfare (Sulllivan, 2002, Sullivan et al, 2002, 2003, 2006). It has five main components:

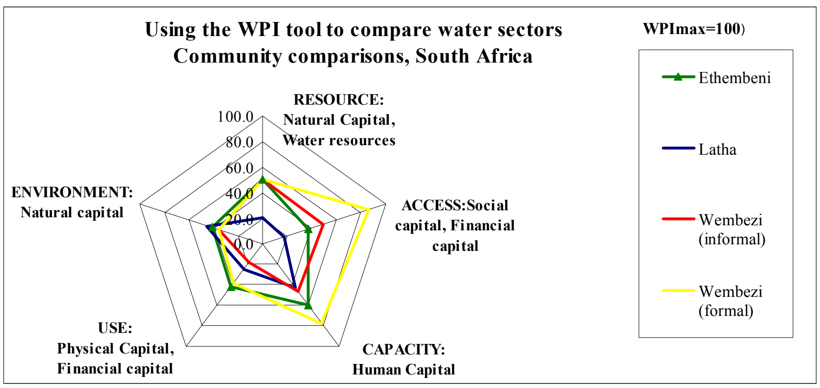
- Resources
- Access
- Capacity
- Use
- Environment

This index is designed to be easy to calculate, and shows a locations situation relative to all places measured, making it useful for comparative and monitoring purposes. Within each of the five components, sub-component indices are averaged to get the component index, and the final index score for the WPI is in the range 0 to 100. The WPI is designed to be applied at any scale, and it is most likely to be used for water management purposes at the municipal or provincial scale. An illustration of how information on the WPI is displayed in Figure 16. This example shows how different communities can be compared on the different components of the Water Poverty Index. By comparing the components, the priorities for development in each community may be identified.

Figure 16: WPI values for selected communities

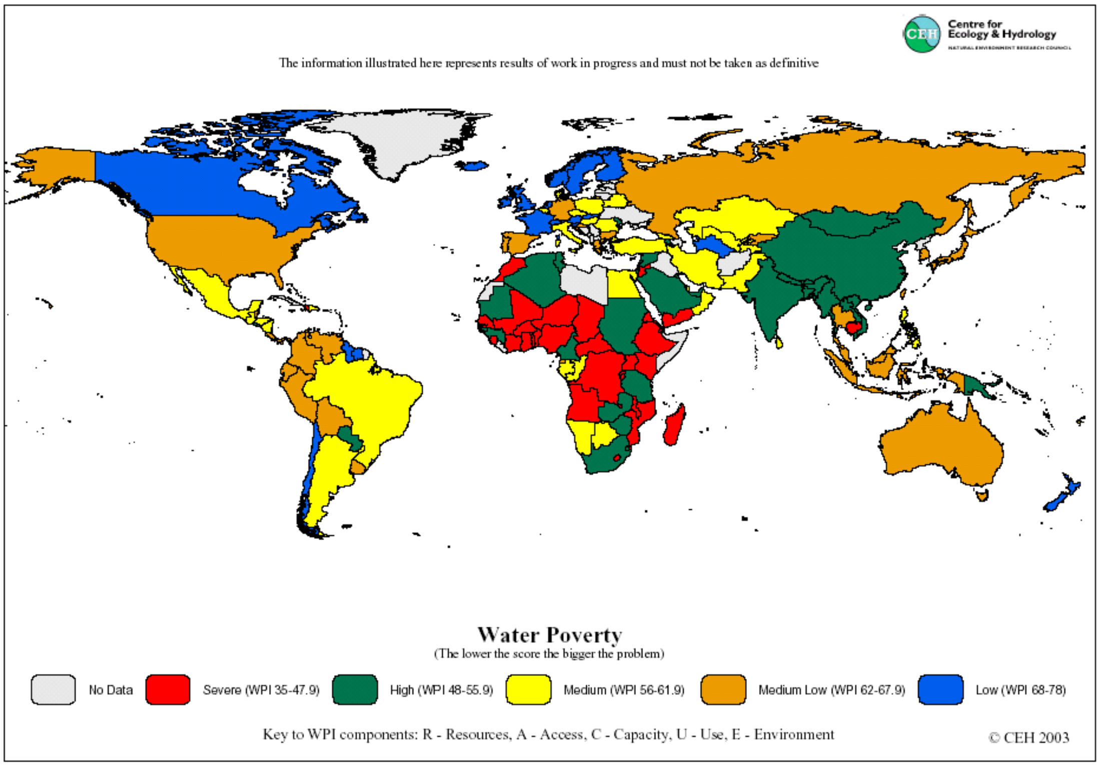
Community values of the WPI in South Africa

Village	RESOURCE: Natural Capital, Water resources	ACCESS:Social capital, Financial capital	CAPACITY: Human Capital	USE: Physical Capital, Financial capital	ENVIRONMENT: Natural capital	WPI
RURAL						
Ethembeni	50.0	36.6	59.8	41.5	41.1	45.8
Latha	20.0	17.0	42.1	24.5	45.1	29.7
URBAN						
Wembezi (informal)	50.0	48.8	46.1	18.0	35.5	39.7
Wembezi (formal)	50.0	86.5	78.0	38.1	35.5	57.6



For decision making in donor agencies, national values can be useful for comparative purposes, and WPI values for 148 countries are shown in Figure 17.

Figure 17: National Water Poverty Index (WPI) values



Source: Sullivan et al., 2002

While information at this scale is useful for international dialogue etc. it is less useful for actual water management due to the high degree of variability that occurs within every country. Sub national scale analysis is much more useful for management purposes, and in the development of the Aquastress Water Stress Index, we aim to produce a tool that can be applied (like the WPI), at any scale.

The Human Development Index (HDI)

While not directly linked to water, the HDI measures the average achievements in a country in three basic dimensions of human development:

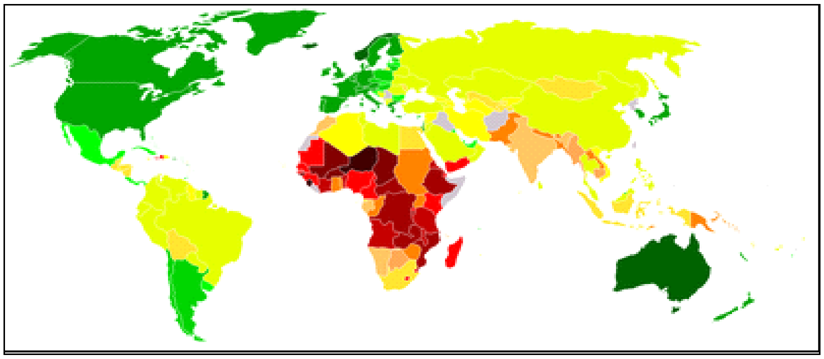
A long and healthy life, as measured by life expectancy at birth.

Knowledge, as measured by the adult literacy rate (with two-thirds weight) and the combined primary, secondary, and tertiary gross enrolment ratio (with one-third weight).

A decent standard of living, as measured by gross domestic product (GDP) per capita at purchasing power parity (PPP) in USD.

Originally developed by Mahbub ul-Haq, the index has been used since 1993 by the United Nations Human Development Program, which issues an annual report. Because of continual improvements in the statistical measures used to determine the score, comparisons of scores or ranks from reports in different years is problematical, if suggestive. The rank of countries has been by far the most popularized use of the index, but the scores themselves are actually much more revealing, as the examples below demonstrate. It was in response to the lack of water inclusion in this important Index, that the Water Poverty Index has been developed, and consultation with Dr. Richard Jolly, who was involved in the operationalisation of the HDI took place in the early stages of that work.

Figure 18: Human Development Index (2003)



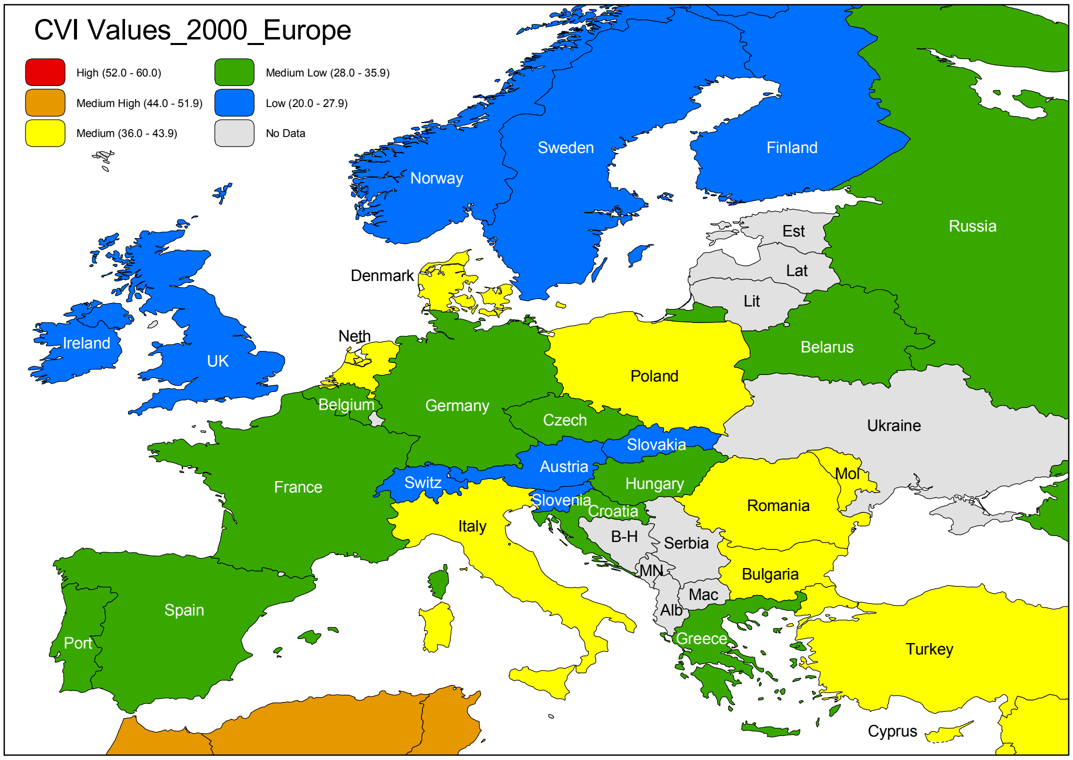
The colours represent the different levels of development (like in a traffic-light: green belongs to the most developed and dark red to the less developed). Each year, UN member states are listed and ranked according to these measures.

The Climate Vulnerability Index (CVI)

The WPI has been extended to take account of climate change, and this has arisen in the development of the Climate Vulnerability Index (CVI), which is based on the assumption that poverty is a key driver of vulnerability, and water resources are influenced by climate and other global changes (Sullivan and Meigh, 2005). Through the addition of a further geospatial component, and the application of scenarios of future changes, the scores can be used to examine potential impacts of global change on water resources and the other dimensions of the CVI structure.

The advantage of this approach is that the application of scenarios means that the tool can be used to explore the potential impacts of change. While major global changes may result from climate impacts, these changes will also result from other socio-economic factors such as population growth, economic development and international trade. All of these will impact on water resources, and that will in turn influence the vulnerability of human populations. The value of the CVI as a tool to highlight different conditions in different places, is illustrated in Figure 19, showing the variation in scores across western Europe.

Figure 19: Illustrating the CVI values for Western Europe



C. CONSIDERING NON-LINEAR MODELS FOR THE AWSI

If it were considered important to moderate the influence of some criteria where these might be counted as indicating that that particular aspect is sufficient, it is possible to address that using various non linear combinations of the su-criteria or variables. Some types of non-linear weighting can be devised which will implement either of the two requirements:

(i) to emphasize sites which have a relatively large shortfall in a least one sub-index;

(ii) to emphasize sites which have a relatively large benefit in a least one sub-index.

Let the sub-indices be EMBED Equation.3 , each being a number on the scale 0 to 100, and suppose there are re EMBED Equation.3 of them.

Then combined indices of type (i) are

(a) $$L_1 = 100 - \sqrt{\left\{ n^{-1} \sum_{i=1}^{n} (100 - X_i)^2 \right\}}$$

(b) $$L_2 = \left\{ n^{-1} \sum_{i=1}^{n} \sqrt{X_i} \right\}^2$$

and combined indices of type (ii) are

(a) $$U_1 = \sqrt{\left\{ n^{-1} \sum_{i=1}^{n} (X_i)^2 \right\}}$$

(b) $$U_2 = 100 - \left\{ n^{-1} \sum_{i=1}^{n} \sqrt{100 - X_i} \right\}^2 .$$

These types of combination are essentially equivalent across the two types, with X_i being replaced by $100 - X_i$. The combined indices are structured so that if all the sub-indices take the same value, then the same value is returned for the combined indices. Weighted forms for the first type would be

(a) $$L_1 = 100 - \sqrt{\left\{ \frac{\sum_{i=1}^{n} w_i (100 - X_i)^2}{\sum_{i=1}^{n} w_i} \right\}}$$

(b) $$L_2 = \left\{ \frac{\sum_{i=1}^{n} w_i \sqrt{X_i}}{\sum_{i=1}^{n} w_i} \right\}^2$$

The requirement to give extra emphasis to the two types of extreme can be given stronger effect by replacing the square and square-root operations by cube and cube-roots, or by higher powers

A third form of combination can be devised that has features of both forms. This is most readily written in three stages --

(i) initial transformation:

$$T_i = \sqrt{100^2 - (100 - X_i)^2} = \sqrt{X_i (200 - X_i)^2}$$

(ii) averaging:

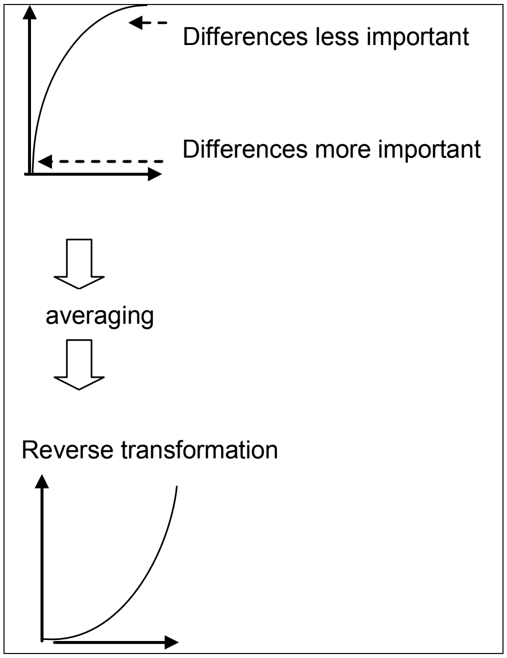
$$S = \frac{\sum_{i=1}^{n} w_i T_i}{\sum_{i=1}^{n} w_i}$$

(iii) back transformation

$$L_3 = 100 - \sqrt{100^2 - S^2} \ .$$

This is illustrated by Figure 20 below:

Figure 20: The impact of data transformation



Some indication of the properties of these combinations ban be gained by trying out a small selection of different sets of sub-index values, each having the same average index (see Table 7: Averaging indices

Table 7: Averaging indices

	Type 1, L_1	Type 2, L_2	Type 3, L_3
50,50,50	50	50	50
0,50,100	35.5	32.4	21.7
0,75,75	38.8	33.3	23.6
25,50,75	46.0	47.8	44.5

This illustrates how the combination formula is an important choice, and the selection of a standardised framework (formula) is an important decision, and the same framework should be used at all sites.

Acknowledgement:

Thanks to Dr. David Jones of CEH for his contribution to this text

D. SUGGESTION FROM CEH FOR A POSSIBLE PROCEDURE FOR BUILDING AND USING THE AQUASTRESS WATER STRESS MATRIX

1. Calculation and application of the AWSM at the test sites

In order to apply the AWSI at the study sites, a number of steps must be carried out. When these steps are completed, the AWSI value can be displayed. At that point, the AWSI can then be inserted into the AWSM matrix. A template for the matrix structure will be provided by WB2.

2. Steps in Calculating the Aquastress Water Stress Index (AWSI)

- collate data
- hold consultation workshop on index structure and weightings
- convert raw data to normalized scores where necessary
- calculate and insert (normalized) sub-index scores into AWSI formula
- determine thresholds for PM and ISWSI and its components
- display results in tables and graphically, (template files to be supplied)

3. Building the Aquastress Water Stress Matrix (AWSM)

- insert AWSI scores and pentagram figure into matrix table.
- use thresholds to assess degree of stress for each sector, and dependency
- generate a map with other information to be added to matrix values
- identify geographic type
- complete commentary of qualitative descriptions of local water stress issues
- provide summary of this information in summary box.
- provide traffic light guidance
- provide photographic support

NOTE: WB 2 will calculate values for the AWSI and AWSM for all sites where possible, but will also provide support for any case site team who wishes to make their own calculations. This activity will be led by CEH. The success of this process will depend on the commitment of members of the JWTs and local stakeholders to participate in the process and on the quality and range of data available.

4. Stakeholder and Practitioner roles roles

During the process of development and use of the AWSM and AWSI, there are particular roles for stakeholder involvement. Primarily, stakeholders will first be involved in selction of most appropriate variables to be used as indicators within the structure of the AWSI calculation, and in addition they will be involved in the determination of thresholds for the AWSI components and Potential Margin. When the AWSI and AWSM are completed, they will then be able to test the approach in practice and provide feedback on the usefulness of the tool at their specific sites.

5. Communication and interpretation

During the process of the application and use of the AWSI and AWSM, the WB2 team will be able to provide assistance on the implementation and interpretation of the information provided within the AWSM, and the specific meaning it will have for the site in question. In this part of the process, there will be a need for close links to be developed with other workblocks of the Aquastress project. .

E. WB2 meetings on the AWSI

Date	Place	Persons present
22nd-23rd-24th May 2006	Wallingford	Caroline Sullivan, Maria Manez, Sonja Schmidt Anna Maria Giacomello, David Inman, Sébastien Loubier, Ad Olsthorn, Silke Panebianco, Elisabetta Preziosi
5th-6th December 2005	Osnabrück	Maria Manez, Caroline Sullivan, Eddy Moors, Claudia Pahl-Wostl, Elisabetta Preziosi, Sonja Schmidt, Isabel van den Wyngaert, Undala Alam, Michiel Blind, Bettina Blümling, Jochen Fröbrich, Matt Hare, David Inman, Ioannis Kountouris, Sébastien Loubier, Sophie Vermooten, Thomas Wintgens, Henk Wolters, Nora Zuberbühler
18th-19th October 2005	Osnabrück	Maria Manez, Caroline Sullivan, Claudia Pahl-Wostl, Sonja Schmidt, Bettina Blümling, Dirk Günther
15^{th}-18^{th} June 2005	Porto	Claudia Pahl-Wostl, Maria Manez Costa, Eddy Moors, Caroline Sullivan, Sonja Schmidt, Rodrigo Maia, Katharina Tarnacki, David Inman, Elisabetta Preziosi, Isabel van den Wyngaert, Melanie Bauer, Matt Hare, Karina Rasche, Sébastien Loubier, Jean-Claude Mailhol, Yorck von Korff , Evan Fraser, Eduardo Vivas, Mariana Lemos, Cristina Silva

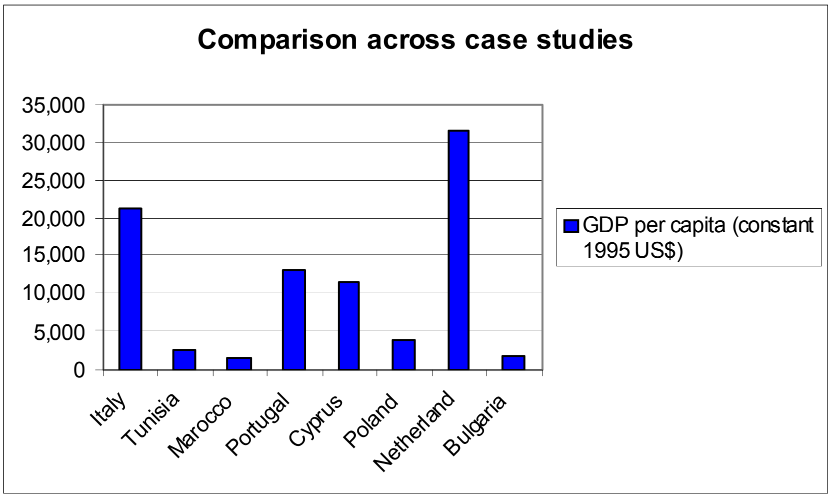
F. GENERAL VARIATIONS BETWEEN AQUASTRESS TEST SITES

There is much evidence that water resource allocation is neither rational or equitable. It is an issue which cannot be modelled with a rigid deterministic approach. Water management is a political issue, and the provision of information to support that process is very relevant and important. The AWSM (and the related AWSI) will both provide that, but the impact of this tool on the sites will depend very much on the nature of these sites. For the benefit of a lay reader who is not familiar with the Aquastress test sites, some general information about all the sites is included here.

The Aquastress sites are very variable, but they all display an interesting dimension of water stress. Due to the variations between sites however, it is important to consider the different causes of water stress and the different conditions under which they may be addressed. Some of the variations in the study sites are outlined in this section, to provide a background to the range of policy conditions which need to be addressed in this work.

Economic variation

Following figure shows the variation in GDP across the countries where the study sites are located, and this indicates the type of economy in which any stress mitigation option were to be applied. From these figures, we can see that potential internal revenue to fund mitigation schemes will be limited, and thus in terms of the sustainability of any option, the operation and maintenance costs must be in keeping with the kinds of economies they are designed for.

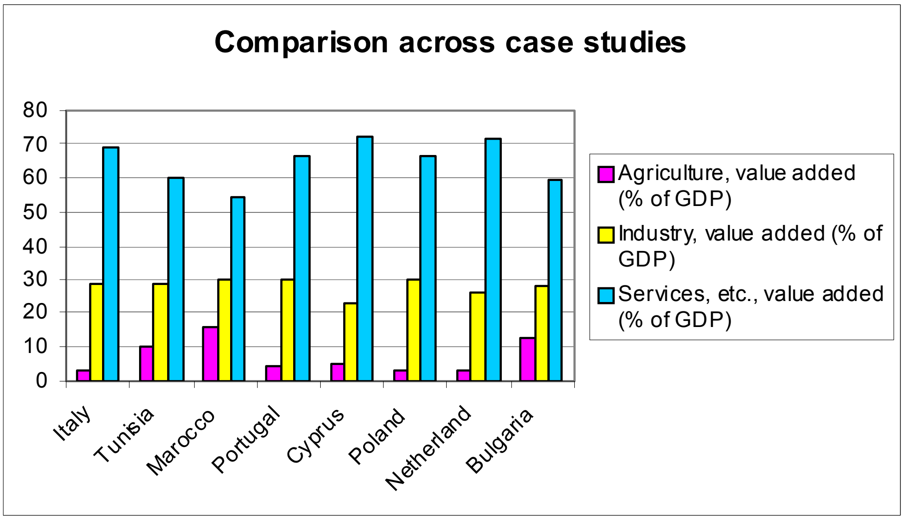


There are also wide differences between the study site countries in terms of the composition of their national income. This is demonstrated Figure 21, where the relative proportions of GDP generated per sector is shown. This indicates that in all of the economies of the study sites, agriculture is significantly less important economically[1], than both industry and services. This suggests that the consideration of water stress mitigation options must consider the likelihood of changes in consumption patters, as these economies evolve.

[1] This term is used here to mean its importance as measured by a monetary input into the recorded national accounts. Of course in all agricultural contexts, there is also an unaccounted for part of output which in addition to its financial value, has an important social value which is not reflected here.

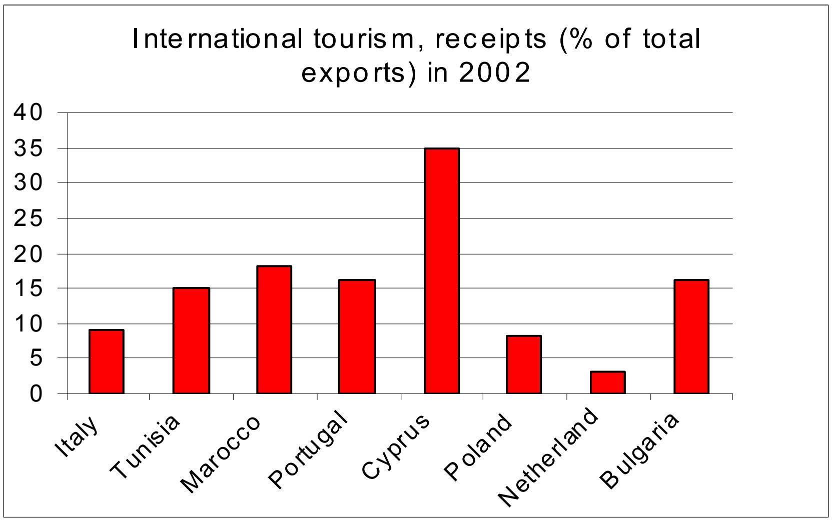
Changes in water consumption associated with economic development are likely to lead to an increase in water stress, unless strict water saving regulations and technologies are brought into being. This suggests that water consumption may serve as an effective indicator of water stress. WB2 however has concluded that a simple measure like that will not capture the range of issues which need to be addressed.

Figure 21: Sectoral contributions to GDP



The impact of these structural changes in the macro-economic conditions of the study site countries can be illustrated through an examination of the role of tourism in each country. This is shown in Figure 22, and again this demonstrates the need for a revision of priorities in water allocation decisions, if overall water use efficiency (in terms of GDP generation), is to be maximised. This would be a logical policy choice in the face of water stress. The AWSI will address these choices by providing details of how they may impact on water stress, (by means of the index).

Figure 22: The contribution of tourism receipts to export revenue



As can be seen in Figure 22, Cyprus is most dependent economically on tourism receipts, although both Bulgaria and Morocco also earn a significant amount of foreign exchange through that source. This would imply that these countries would need to consider measures to specifically address water stress problems in that sector.

Hydrological variation

The rainfall regimes in the study sites are illustrated in Figure 23, and this demonstrates the variability of natural baseline conditions faced in the sites. Some sites (such Tadla, for example, are much more dependent on external water sources (through a piped transfer), than other sites where most water comes from the local rainfall regime. Again, this implies that stress mitigation options relating to sites of the former type may involve a greater commitment to major water transfer infrastructure than other situations. This may however also indicate that more cost effective measures in such sites may involve greater public awareness raising, land use control etc to avoid such high infrastructure costs.

Figure 23: Rainfall regimes in the test sites

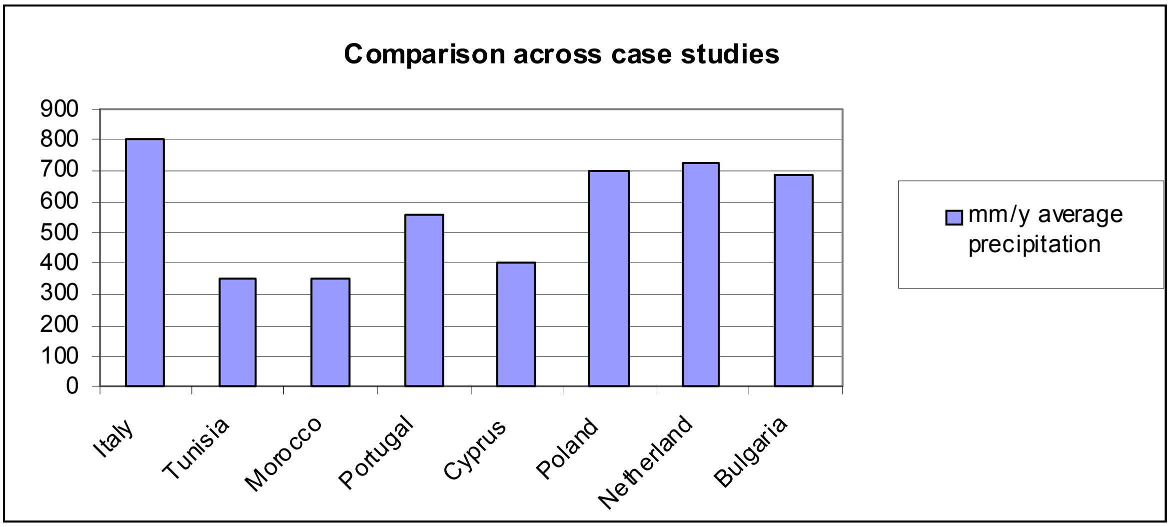


Table 8 shows how scores on the same variable indicate different positions at the various test sites. The advantage of using a standardised set of indicators is that comparison becomes possible between sites, as well as at the same site over time.

Table 8: Selected indicator values from four test sites

INDICATOR #	Definition	Flumendosa		Guadiana		Iskar		Tadla	
		YES/NO	Q / Q	YES/NO	Q / Q	YES/NO	Q / Q	YES/NO	Q / Q
1	Supply interruptions	Y	47.3% (yr2000)	Y	?	Y	? (most of population 1 in 3 days (yr 1995)	Y	
2	% Domestic consumption as a fraction of the total		40		8-9%		73%		?
3	Per capita consumption (litres/capita/day) variation over the last 10 yrs	increasing	352	increasing	185 (Algarve) 210 Alentejo	increasing	656 (including leakage)	increasing	138
4	% Losses in infrastructure network	Y	40%	Y	37%	Y	57%	Y	?
5	Per capita investment in demand management and water treatment	?		?		Y (research)	?	Y (Casablanca)	?
6	Existence of a government department devoted to handling customer complaints	?		?		Y		?	
7	% of population who have no formal access to water supply	?	?		10-15%		2%		10%, rural - 85%
8	% of urban households not connected to effective sewerage systems	?	?		20%		80%		85%

This table illustrates the variability in data between sites. This will have important implications for the work to be done at the various test sites.

Water stress problems in the case study sites

On the basis of other outputs from the Aquastress project, a list of potential problems for each study site has been developed. The cases in the Aquastress project have been identified as been representative of a range of problems associated with water stress. The proposed Aquastress Water Stress Index and Matrix have been designed to take account of a range of the kinds of issues anticipated at the various sites. Some of these are highlighted in Table 9 below:

Table 9: Potential problems of selected test sites

Study site	Possible problems for mitigation
Iskar	▪ Pollution from metallurgical plant Kremikovtzi ▪ Reduce the domestic water demand in Sofia ▪ Crisis management (drought and floods)
Guadiana General problems: proposed case study site	▪ Pollution loads due to agriculture ▪ Transboundary basin management (pollution, diversion from Spain) ▪ High demand for tourism ▪ Insufficient supply in dry periods ▪ Impacts of EU agriculture policy on water ▪ Optimisation of GW and SW sustainable use ▪ Water transfer to Ribeira de Algarve ▪ Sustainable water resources use
Flumendosa proposed case study site	▪ Improving irrigation schemes and management of agricultural practice to decrease the discharge of pollutants
Limassol Main problems:	▪ Aquifer depletion ▪ Sea water intrusion ▪ Sea level

Proposed case studies	▪ GW overexplotation ▪ Promote the use of recycled water
Mergeullil (general)	▪ Limited resources ▪ Overexploitation ▪ No management
Tadla	▪ Aquifer overexploitation ▪ Degradation of water quality ▪ Low outflow to the sea at the river basin scale (100% consumed)

A number of existing Aquastress outputs can shed some light on some of these issues.