Defining rational use of water in Mediterranean irrigation

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Abstract. Rational use of water (RUW) is a catch-all term that takes in a wide variety of water use dimensions and is a frequently referred to in water planning, science and the public debate. In spite of this general adoption, the term lacks a unitary conceptual foundation. The aim of the paper is to provide a conceptual starting point for developing a practical working definition of RUW in the context of irrigation in the Mediterranean in order to facilitate dialogue and water negotiations. The paper shows that the concept of RUW is relevant to irrigation as water scarcity and pressures on water are increasing. At a micro-level (household, farm and community level), the definition includes maximising profit, water use efficiency and productivity; at a meso-level (institutions, river basin, infrastructure) to achieve an equitable and economic efficient allocation that does not increase the conflict level between competing uses; while at a macro-level (legal, national and international policy) sustainability and food security appear to be core aspects of RUW. Although multi-dimensional indicator have advantages, they are also rather complex. The paper therefore presents a number of single dimensional indicators that can potentially be used to measure RUW.

Keywords. Irrigation – Efficiency – Productivity – Indicators

Définition d'une utilisation rationnelle de l'eau pour l'irrigation en Méditerranée

Résumé. *L'utilisation rationnelle de l'eau (UReau) est un terme générique recouvrant une large variété de dimensions de l'utilisation de l'eau. La gestion de l'eau, les sciences de l'eau et le débat public font référence à ce terme. Bien que largement usité, il ne désigne pas une notion conceptuelle unitaire. Le but de ce document de réflexion est de fournir un point de départ conceptuel au développement d'une définition de travail pratique de l'UReau dans le contexte de l'irrigation en Méditerranée afin de faciliter le dialogue et les négociations sur l'eau. Ce document de réflexion montre que le concept d'UReau revêt une grande importance pour l'irrigation en raison de la raréfaction des ressources en eau et des pressions croissantes sur ces ressources. Au niveau local (ménages, fermes, populations locales), la définition inclut la maximisation de la rentabilité, de l'efficacité de l'utilisation de l'eau et de la productivité. Au niveau intermédiaire (collectivités, bassins fluviaux, infrastructure), l'objectif est de réaliser une distribution équitable et économiquement efficace qui n'augmente pas le niveau de conflit entre les utilisations concurrentes. Au niveau global (politiques légales, nationales et internationales), la durabilité et la sécurité alimentaire sont des aspects clés de l'UReau. Bien que des indicateurs multidimensionnels offrent des avantages, ils sont également complexes. Ce document de réflexion présente par conséquent un certain nombre d'indicateurs unidimensionnels susceptibles d'être utilisés pour mesurer l'UReau.*

Mots clés. *Irrigation – Efficience – Productivité – Indicateurs*

I – Background

> *'Water is abundant globally but scarce locally.'*
>
> *Rosegrant (1995)*

1. Water scarcity in the Mediterranean region

The Mediterranean region comprises the countries surrounding the Mediterranean Sea (plus Portugal)[1]. The Mediterranean Sea literally means the 'sea between lands'. It is the largest of the semi-enclosed European seas and it is surrounded by 22 riparian countries and territories having shores on three continents (Europe, Africa and Asia). In 2008 these countries and territories accounted for 5.7% of the world's land mass and 7% of the world's population with 460 million people out of which two thirds are urban; 60% of the population of the world's 'water-poor' countries; 12% of world GDP[2]; 30% of international tourism with 275 million visitors; and 8% of global CO_2 emissions. Moreover, the Mediterranean water demand has doubled since 1950 to reach 280 km^3 per year in 2007 (UNEP/MAP-Plan Bleu, 2009). Within this region, the Middle East and North Africa are the most water-scarce regions of the World. The aquifers are over-exploited; water quality is worsening and water supply is often restricted affecting human health, agricultural productivity and the environment. Water scarcity leads to tensions within communities and migration in search of better opportunities. As the population grows in this region, per capita water availability is expected to decrease by 50% by 2050 and climate change is predicted to result in more frequent and severe droughts and floods (The World Bank, 2007). In recent years, there has been a growing concern throughout the Mediterranean region regarding drought events leading to water scarcity problems. Here, the semi-arid/arid climate enhances water scarcity and rainfall is the main source of recharge. The competition between various uses, especially agriculture and tourism, is high in this area that relies on both for its GDP. Hence, conflicts over water are increasing and they are complex, involving competition among alternative uses, among geographical regions with disparate water endowments, and between water resource development and other natural resources lost due to that development. The challenge of water use and allocation is already a major political concern and will most likely amplify in the coming years. 'Integrated water resource management' is high on the policy agenda and affects people in their daily life. As the water resource is becoming scarce and/or is deteriorating, it becomes clear that plentiful water of good quality can no longer be free to all who desire to use it and a more in-depth understanding of water resource use and its consequences is needed.

2. Irrigation trends

At a global level, agriculture is by far the largest user of water diverted by man. In the Mediterranean region agriculture accounts for 64% of total water demand, followed by industry (including the energy sector) at 22% and the domestic sector with 14%. Crop production is essentially rain-fed. Irrigation water demand varies from 5,000 m^3 ha^{-1} per year in the north to almost twice that much (9,600 m^3 ha^{-1} per year) in the south and east (UNEP/MAP-Plan Bleu, 2009), depending on irrigation techniques, water use efficiency and climate conditions. Irrigation water accounts for over 50% of water use in all countries in the region apart from those in the eastern Adriatic and France, reaching almost 90% in Syria and Morocco (see Annex 2). The countries or territories in the region share many common features including: arid and semi-arid climate with hot summers, mild winters, and wet falls and springs; limited water resources, agricultural development limited by water availability and high socio-economic value of water. Crop production is in particular vulnerable to climate change due to predicted deficits in available water resources and threats of farm land degradation. In April 2009 the European Commission published the White Paper: 'Adapting to climate change: Towards a European framework for action'. This policy paper presents the framework for adaptation measures and policies to reduce the European Union's vulnerability to the impacts of climate change, including specific strategies aimed at agriculture. Most of these adaption measures are aimed at national, regional or local level to address the regional variability and severity of climate change impact. Several studies show that the efficiency of water use in agriculture is low[3], though some locations and crops have high efficiency and productivity (Berbel *et al.,* 2011a). Still, to improve water use is crucial for the Mediterranean irrigation. Although 'rational use of water' (RUW) is a term that is frequently referred to in water planning, science and the public debate when water grows scarce, it continues to be an ill-defined catch-all term that takes in a wide variety of water use dimensions as it lacks a unitary conceptual foundation. The aim of the paper is to provide a conceptual starting point for developing a practical working definition on RUW in the context of irrigation in the Mediterranean region to facilitate dialogue and water negotiations[4].

The paper is divided into four parts. First, a background on Mediterranean water resources and irrigation is given. Second, we continue with a review of the historical-philosophical background of the concept of rationality, followed by an analysis of the dimensions of ´rational use of water´ on, respectively, a micro-, meso- and macro-level. Third, we describe selected indictors that could be used to define the rational use of irrigation water in terms of efficiency and productivity. Fourth, and last, we present some concluding remarks.

II – Rationality

'The irrationality of a thing is no argument against its existence, rather a condition of it.'
Friedrich Nietzsche (1844 - 1900)

1. What is understood by rationality?

Rationality normally refers to human or institutional behaviour or situations where decisions are involved. If a chosen action or means is favourable to accomplish a purpose or goal, they are regarded rational; otherwise, they are regarded irrational. Behaviour which is arbitrary or random is normally judged as irrational. Nevertheless, purposes and goals can themselves be judged rational or irrational, with reference to other relevant means-ends relationships. In economics, sociology and political science, a decision or situation is often considered rational if it is considered optimal, and individuals or institutions are often called rational if they tend to act somehow optimally in achieving their goals. Regarding rationality in this manner, the individual's goals or motives are taken for granted and not made subject to criticism, ethics, fairness and so on. Hence rationality simply refers to the success of goal realization, whatever that goal consists of. Sometimes, rationality is equated with behaviour that is self-interested to the point of being selfish. It can be claimed that because the goals are not important in definition of rationality, it really only demands logical consistency in choice making.

2. Economic Rationality

In neo-classical economy individuals' preferences are revealed by the choices they make and efficiency and consistency of choice reflect rational behaviour. The criteria of social interest is usually expressed in terms of the pareto criterion where a pareto optimum situation is one where it is impossible to make any individual better off (´more preferred´) without making someone else worse off (´less preferred´). Critics to neo-classical theory of self-interested rationality argue that individuals are capable of altruistic acts and that an extended notion of rationality is necessary (Pearce and Turner 1990). Extended rationality could be understood in terms of multiple preferences rankings within a single individual – one self-interested and the other altruistic (group interested). As a result, moral considerations will then determine a ´meta-ranking´ of alternative motivation where the individuals possess a sense of community which is reflected in a willingness to view assets and resources as common pool. This extended rationality also generates a strong commitment to abide by particular laws which are seen by the individual as endorsing an individual's meta-preferences, despite a potential conflict between the law and the narrow-self interest (Ibid.). Thus, a choice is rational if it is consistent with the objectives and preferences of those making the decision, given the available information. An allocation choice is economically rational if it is seen as yielding a benefit that exceeds the opportunity cost. In other words: when a choice is made from among competing options that is anticipated to yield net benefits that exceed the opportunity cost. When a scarce resource, good, or service is allocated to one use, the opportunity cost of that allocation represents the value of the best alternative that was foregone.

From the perspective of economics, individuals are sometimes considered to have perfect or at least bounded rationality: that is, they always act in a rational way, and are capable of arbitrarily complex deductions towards that end. That is to say, they will always be capable of thinking through all possible outcomes and choosing the best possible thing to do (full information). Economic rationality is closely related to economic efficiency which is a general term to capture the amount of waste or other undesirable features. Herbert Simon introduced the term bounded rationality in the 1950s to designate rational choice that takes into account the cognitive limitations of both knowledge and cognitive capacity (See e.g. Simon, 1982). Hence, theories of bounded rationality relax one or more assumptions of classical utility theory. Bounded rationality is an important theme in behavioural economics and it is related to how the actual decision-making process influences decisions. Kahneman and Tversky (1979) developed the prospect theory that can be seen as an alternative to expected utility theory and aims at modelling real-life choices, rather than optimal decisions. In summary this theory claims that people's attitudes toward risks concerning gains may be quite different from their attitudes toward risks concerning losses. Though this is not necessarily irrational, it is important for analysts to acknowledge the asymmetry of human choices.

3. Rational Use of Water

> *'All science depends on its concepts. These are ideas which receive names.*
> *They determine the questions one asks,*
> *and the answers one gets. They are more fundamental than the theories which are stated in terms of them.'*
> *Sir G. Thompson (1892 – 1975).*

Water demand management under scarcity is challenging. Improved performance in water use and water saving is key to meet the general objectives of economic efficiency, environmental conservation and community/consumer satisfaction. Socially, efficiency looks after the interests of future generations; environmentally, sustainable use of water ensures good ecological status and minimum flows; and economically, water efficiency reduces business costs and defers costly investment in water supply development and sewage treatment capacity expansions. Water policy should be designed in a way that reduces the conflict level between competing uses and ensures environmental sustainability. As stated before, RUW is commonly referred to, but is not a very well defined general concept. What RUW is depends upon the academic field we refer to, stakeholder groups, what level we operate and the interdependence between these levels.

For defining RUW for the irrigation sector we suggest three different levels of analysis:

a. Micro-level (household, farm and community);
b. Meso-level (infrastructure, institutions, river basin); and
c. Macro-level (legal, national and international policy).

On a micro-level, household, farm and community level, the main objective is water productivity and efficient use of water; on a meso-level (infrastructure, institutions, river basin) the main goal is to achieve a territorial and social efficient and equitable allocation of water and to reduce conflict level between competing uses, while on a macro-level (legal, national and international policy) sustainability and food security are core objectives. Table 1 attempts to give an overview on rationality at different levels for the sector of irrigated agriculture.

Table 1: Micro-, meso- and macro-levels of RUW in irrigated agriculture.

Level	Type	Field of Research	Rationality	Research objective
MICRO	Crop	Physiology, agronomy	Optimal use of water	Water efficiency and productivity, drought tolerance
	Plot or Field	Agronomy, hydrology	Maximize resources productivity	Efficiency of irrigation systems and crop management, i.e. minimising losses, maximize technical productivity
	Farm and household	Agronomy, crop level economy, social science	Optimal crop management plan, individual households preferences and capabilities in allocation of productive assets	Livelihood strategies, especially profit maximization and risk minimization.
MESO	Irrigation scheme	Agriculture Engineering	Technical and economical	Irrigation efficiency and cost minimization
	Basin	Socio-economic and environmental science	Economical, social, environmental, territorial, cultural (water rights) and regional.	Efficient and equitable water allocation, hydrological models (basins and aquifers), conflicting environmental and socio-economic objectives
	Institutions	Social science	Social efficiency[a]	Maximize present value of stakeholders benefits, public choice models, conflict resolution
MACRO	Country	Socio-economic policy	Economic and social allocation	Transfer conflicts, food security and maximize economic and social welfare
	International	International policy	Political consensus	Fairness, ethics
	Planet	Sustainability, climate change	Ethics and comparative advantages	Global sustainability

[a] *Many vital socio-cultural and environmental benefits cannot be monetized, and these would have to be taken into account in order to judge what Barbier (1990) calls the "social efficiency" of the system.*

A. Micro level

At field and community level, water is by many considered a main production factor and RUW is often closely linked to efficiency and productivity of water. Efficiency generally refers to the condition of minimal waste (Hackett, 1998) and productivity, normally, is a ratio referring to the unit of output per unit of input (Kijne *et al.,* 2002). The term water efficiency was probably first introduced by Viets (1966). In economic terms what we are looking at is a ratio between a desired output (yield, economic returns) and a parameter estimating input use. However, because of the different connotation attached to the term 'efficiency', some authors claim that it has outlived its usefulness (see e.g. Seckler *et al.,* 2003). Economists refer to total factor productivity as the value of output divided by the value of all inputs. However, the concept of partial productivity is widely used by economists and non-economists alike. Water productivity can be expressed in general physical or economic terms as follows (Seckler *et al.,* 1998):

- Pure physical productivity: quantity of the product divided by the amount of water depleted or diverted.
- Combined physical and economic productivity: either the gross or net present value of the crop divided by the amount of water diverted or depleted.
- Economic productivity: gross or net present value of the product divided by the value of the water diverted or depleted, which can be defined in terms of its value or opportunity cost in the highest alternative use.

Zoebl (2006) argues that the term water productivity is not always meaningful or appropriate to use and should be reserved for genuine production factors such as labour, land and capital. Furthermore, in contrast to fertilizers, pesticides and animal feeds, irrigation water is generally not a purchased input provided by individuals or corporations (Zoebl, 2002). He claims that irrigation efficiency and water use efficiency are still useful and meaningful terms given that they are well defined and used at the level of individual farmers (Zoebl 2006). Alternative concepts have been introduced in recent years, e.g. consumed fraction (Willardson *et al.,* 1994); beneficial and non-beneficial depleted or consumed fractions (Perry 1996; Clemmens and Burt 1997; and Molden 1997). These new terminologies are used in the context of water accounting relating to the engineers view of 'efficiency', though the definition and interpretation of these new terminologies still remain to be widely understood.

Rain-fed agriculture predominates in the Mediterranean region; however, it is on irrigated land that the highest productivity gains have been obtained. Accordingly, although the areas of arable land and permanent crops tended overall to stabilise if not decline from 1961-2005, the annual average growth rate for irrigated land remained unchanged and the total irrigated area in the Mediterranean countries has thus doubled in 40 years to exceed 26 million hectares in 2005, i.e. over 20% of all land under cultivation. Albeit that total agricultural production in the Southern and Eastern Mediterranean countries (SEMCs) has made a huge progress over the past 40 years through improved forms of production; yet, these countries are more and more dependent on secure food supplies (UNEP/MAP-Plan Bleu, 2009).

According to the neoclassical definition of externalities, most water problems in irrigation sector stem from situations where clear misalignments exist between farmers' private objectives and more general social objectives. The presence of divergences between private and social objectives is manifested by various trends. One is the widening of the divergence between farmers' low water marginal productivity in irrigated commodity production and the sum of the costs incurred by society for making the resources available to them (except for the case of high-value crops). Another is the confirmation that the water costs of competing users may be rising as a result of farmers' water use or polluting practices.

The manifestation of adverse incentives is perceived through time and not with snapshots. This implies that policy judgments should preferably be based on whether observed trends show improvements or are worsening, however, consistent time-series data are often difficult to obtain.

B. Meso- level

At meso- or intermediate-level we consider structures, institutions and river basin. Irrigation systems in many countries will more and more need to find ways to improve performance as the pressure on available water resources is increasing. The need to improve irrigation and drainage sector is driven by several factors (Malano 2004):

- Population growth leading to a need for greater agricultural production
- Increasing water scarcity within river basins leading to a need for irrigated agriculture to produce ‘more crop per drop’
- Higher expectations from farmers and their families to their livelihoods
- Higher expectations by farmers of the level of service provided by the irrigation and drainage agency
- Changing perceptions, attitudes and practices within government on provision of public services.

People engage in irrigation to secure their basic needs and to earn income; however their activities depend greatly on their access to land, labour, water, markets, knowledge and capital, which are the main resources in irrigated agriculture. Within any given culture, access to resources varies according to gender, age, wealth, caste and ethnicity, and therefore, so does livelihood. When water is locked into uses that are no longer high-valued inefficiency abounds, or when the distribution of resource use cannot adapt to changing economic conditions conflicts increases. In most places in the world, water has up till now been treated as a free resource to the effect that no charge is imposed for withdrawing water from a surface or groundwater source. The users have only paid for the transport of water from its source to its place of use, and sometimes for treatment of the water and disposal of the return flows. Traditionally, restrictions in many areas have limited or banned the possibilities of water users to trade or sell their water rights. Water rights systems in many places have allocated water rights based on historical claims. Traditional water right systems often gave many water users a low incentive to increase their water use efficiency, particular for those with historical rights. The introduction of water markets could allow water users to sell the unused share of their water rights to another user, providing an incentive to improve the efficiency of their water use (Schoengold and Zilberman, 2004).

C. Macro level

At the macro level, international and national policies determine resource availability and distribution, such as water resource policies; international funding and loan agreements; legal arrangements, etc. A policy can be Pareto-efficient compared to the status quo when it makes some people better off and nobody worse off. In contrast, a proposed policy is potentially Pareto efficient compared to the status quo when it generates net social benefits that could potentially be used to compensate those made worse off.

In year 2000, the European Union[5] adopted the Water Framework Directive (WFD) as a response to the numerous, and increasing, pressures on the European water resources. The Directive (2000/60/EC) is probably the most ambitious effort for a common integrated management of natural resources in the union (Berbel and Gutiérrez, 2004) and sets the clear objective that ‘good status’ must be achieved for all European waters by 2015. The Water Framework Directive proposes regulating the use of water and of associated areas on the basis of their capacity to withstand different kinds of pressures and impacts. It thus intends to promote and guarantee a responsible, rational and sustainable exploitation and use of the environment:

> ‘*As set out in Article 174 of the Treaty, the Community policy on the environment is to contribute to the pursuit of the objectives of preserving, protecting and improving the quality of the environment, in prudent and rational utilisation of natural resources, and to be based on the precautionary principle and on the principles that preventive action should be taken, environmental damage should, as a priority, be rectified at source and that the polluter should pay.* ’
>
> (European Commission, 2000, L327/2)

Other international agreements include: the Millennium Development Goals (safe and sufficient water) and Agenda 21:

> *"…to plan for the sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of national economic development policy"*

In most international agreements, rationality is strongly linked to sustainability. A community's control and prudent use of natural, human, human-made, social, and cultural capital to foster economic security and vitality, social and political democracy, and ecological integrity for present and future generations. Ecological sustainability more narrowly focuses on maintaining and enhancing ecological integrity and biodiversity, and generally on protecting the life-support and waste-sink functions of the earth. The most often quoted definition of Integrated Water Resource Management (IWRM) has been developed by the Global Water Partnership (GWP);

> *'…a process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.'*
>
> (GWP-TAC, 2000)

This definition has been criticised to be very limited for practical guidance to present and future water management practices, though all encompassing and impressive (Biswas, 2004).

We see from this chapter that planners must be aware of resources and constraints at all three levels (macro, intermediate and micro) in order to determine which changes are needed at each level. Rationality depends upon the level of pressure, stakeholders, science, the quality of water, property rights, norms and moral (fairness) and ecological minimum standards. Stakeholders need to get involved to comply with human rights considerations. To improve the theoretical framework for policy considerations and methodology on water use, analytical frameworks such as the logical framework analysis and sustainable livelihoods analysis could potentially be used. The logical framework approach is a management tool mainly used in the design, monitoring and evaluation of international development projects while the livelihoods analysis provides a framework for research and policy that takes into account the complex and multidimensional relationships between the social and physical environments.

III – Efficiency and productivity indicators

> *'Efficiency is intelligent laziness.'*
>
> *David Dunham*

1. Methods

The key issue in defining efficiency and productivity indicators is related to answering the following questions, which are closely related to the level of analysis (micro, meso or macro-level):

- Who is the decision maker (farmer, administration, etc.) and what are the decision making objectives (profit, employment, risk reduction, etc.)?
- What are the limiting resources (land, labour, capital, water, etc.)?
- How is the decision making model (data quality and availability, time-span, etc.)?

Then, generally, water efficiency and productivity is defined in the literature in relation to micro- and meso-level. Also, the definitions are single dimensional, i.e. the authors give a list of output ratios (economic, physical, etc.) versus inputs (water, fertilizer, etc.). This paper uses these definitions as they are the most general used in literature regarding irrigation efficiency, nevertheless there are more complex definitions that take into account more than one objective (multi-criteria analysis or MCA) and ; data envelop analysis (DEA) where analysis is done based upon combination of various inputs to give one or more outputs. For a complete review of MCA in irrigation economics, see Gomez-Limon *et al.* (2007), regarding DEA, see e.g. Malano *et al.* (2004) and the paper in this volume by Giannoccaro *et al.,* Other attributes to the problem such as irreversibility, equity, minimising uncertainty, etc. may also be introduced in the analysis. Cost-effectiveness analysis (CEA) and cost benefit analysis (CBA) could also be considered. The cost-effectiveness approach is in WFD considered a management and planning instrument when formulating the program of measures to be implemented in the European river basins (Berbel *et al.,* 2011b) and could be relevant to all scales (national, river basin, local).

All the above mentioned methods (MCA, DEA, CEA, CBA) imply a further complexity to the analysis of efficiency. For these methods we may set as a common ground the concept of bounded rationality (Simon, 1982), so that instead of an ‘optimum’ solution, the aim is to find a ‘satisfactory’ solution between different and conflicting objectives. A farmer, when deciding on water allocation to crops, may be interested in maximizing profits and minimizing risk, or minimizing cost of labour. A solution to this multi-criteria problem needs to be analysed under multi-attribute utility. The result may be that the revealed solution may look non-optimal (non-rational) from the single profit maximizing hypothesis. This makes the practical definition of rational choices more complex, but nevertheless we should go beyond this problem in order to find practical definitions of RUW. These methods are outside the scope of this paper, consequently, this document is focused on the simplest approach which is single dimensional ratios.

2. Irrigation and hydrological cycle

‘Irrigation’ can be defined as the artificial supply of water to supplement or substitute natural precipitation for agricultural production (Bazza, 2006). ‘Precipitation’ can be defined as all deposits on the earth of hail, mist, rain, sleet, snow, dew, fog, frost, and dust[6]. Generally the rainy season over the Mediterranean Sea extends from October to March, with maximum rainfall taking place during November to December. The average rain rate is ~1–2 mm day−1, but during the rainy season there is 20% larger rainfall over the western than that over the eastern Mediterranean Sea (Mehta and Yang, 2008). Precipitation is also a critical variable to evaluate regional and global water supplies and time variability. It characterizes the input of water into the entire hydrological system that is important for a variety of models including climate, weather, ecosystem, hydrological and biogeochemical models.

Currently, the number of ‘water-poor’ Mediterranean people (less than 1,000 m^3 per capita per year of renewable water resources) amounts to 180 million (Morocco, Egypt, Cyprus and Syria). Those faced with ‘water shortage’ (less than 500 m^3 per capita per year) amount to 60 million (Malta, Libya, Palestinian Territories, Israel, Algeria and Tunisia). These countries to the south and east have run up a 160% renewable water resources deficit to meet the 1,700 m^3 per capita per year, deemed to be the minimum threshold of water required to fully meet the peoples’ needs (UNEP/MAP-Plan Bleu, 2009). The ‘renewable water resources’ can be estimated on the basis of the water cycle, e.g. they represent the long-term average annual flow of rivers (surface water) and groundwater, while non-renewable water resources are e.g. groundwater bodies or deep aquifers that have a negligible rate of recharge on the human time-scale and thus can be regard as non-renewable (FAO, 2003). ‘Surface water’ can be defined as all waters on the surface of the Earth found in streams, rivers, ponds, lakes, marshes or wetlands, and as ice and snow[7]. ‘Groundwater’ can be defined as all water below the surface of the ground in the saturated zone, commonly referred to as an aquifer, and in direct contact with the ground or subsoil[8]. This zone consist of a subsurface layer, or layers, of rock or other geological strata of sufficient porosity and permeability to allow a significant flow of groundwater or the abstraction of significant quantities of groundwater.

The transpiration ratio is applicable to crop production and was introduced by Van Helmont (1600-1700). The transpiration ratio represents the amount of water used by a crop to reach a certain weight and is the term that later led to the concept of water productivity or the ‘crop per drop’ slogan (Zoebl, 2002). The potential transpiration, introduced by Penman in 1948 (Ibid.), is the water loss from an extended surface of a short green crop, actively growing, completely shading the soil and never short of water. This is applicable to crop and field level. Evaporation is the transition from a liquid to a vapour state. The actual and potential evapotranspiration is the net water loss (in vapour form) per unit area of land, both directly from the land surface, and indirectly through transpiring leaves[9]. Evapotranspiration is applicable to crop and field level and is the sum of evaporation and plant transpiration. The term was introduced by Thornthwaite in 1944 in response to irrigation engineers who did not distinguish between actual and the so-called potential evapotranspiration. However, this difference became less important from the 1960s onwards, after Penman’s formula became the established way to calculate crop water needs by irrigation engineers globally (Zoebl, 2002).

In order to develop standards, it is important to take into consideration: (i) examination of long time series of past-to-present hydrological data (including palaeodata and proxy data, especially for droughts and floods); (ii) do projections into the future (running hydrological models fed by scenarios resulting from climate modelling, and in particular regional climate models, via downscaling); and (iii) monitor extreme hydrological events such as floods and droughts.

In view of population growth and of the immediate impacts of changes in the water cycle, it is estimated that, by 2050, about 290 million people in the SEMC could end up in a situation of water scarcity (Plan Bleu, 2008). When considering uncertainty, we will need to identify critical gaps in knowledge related to climate change and water, as well as interlinked issues of the global environment change. According to Kundzewicz and Mata (n.y.) the existing gaps include, among others:

- scarcity of geophysical data, with sufficient accuracy and spatial and temporal coverage
- scarcity of socio-economic information
- validation and integrated interpretation of proxy data
- credibility and accuracy of hydrologically-relevant outputs from climate models
- credibility and accuracy of downscaling schemes
- development of climate models for hydrological forecasting
- uncertainty in results related to extremes - floods and droughts (frequency, intensity, persistence, spatial extent).

3. Related indicators

> *‘Let not even a small quantity of water that comes from the rain*
> *go to the sea without being made useful to man.’*
> *King Parakramabahu of Sri Lanka (AD 1153-1186)*

Most governmental agencies, international bodies (e.g. FAO) and research institutions set as target for irrigation to manage water efficiently in the agricultural sector, measured as ‘more crop and value per drop’ and recently ‘more jobs per drop’. This target is based upon measuring water use efficiency as a ratio of desired output (physical, economic or social) compared to consumed input. Nevertheless, the application of this intuitive concept should be done with precaution.

The terms 'water use efficiency' (WUE) and 'water productivity' (WP) has been loosely used to describe a number of water use indicators, and irrigation efficiency ratios. Irrigation is frequently said to have a high potential to achieve efficiency gains in the Mediterranean region, due to low efficiency and a general high value of water that allows for investment in water saving technologies. However, improving efficiency in irrigation to alleviate meso- and macro- level water scarcity may not be as significant as one might have thought. The explanation is that many of the frequently used concepts of water use efficiency systematically underestimate the true efficiency (Seckler *et al.,* 2003). For example not all water purportedly 'lost' from a farm or irrigation district in fact represent a loss to the hydrological system, as the water returns to the hydrological system (either surface or groundwater). Losses to the system are strictly losses to the sea, losses through evaporation from e.g. canals, transfers or water being severely polluted. Therefore how we define water and at what scale we refer to is critical to management and decision making.

In general terms, irrigation efficiency is defined as the ratio of water consumed to water supplied and water productivity is the ratio of crop output to water either diverted or consumed, the ratio being expressed in either physical or monetary terms or some combination of the two. Seckler *et al.* (2003) distinguish between 'classical' and 'neoclassical' concepts of irrigation efficiency. Classical irrigation efficiency can be defined as the crop water requirement (actual evotranspiration minus effective precipitation) divided by the water withdrawn or diverted from a specific surface water or groundwater source. The classical concepts of irrigation efficiency ignore the reuse and recycling of water and thus tend to underestimated real basin efficiency while the newer neoclassical concepts such as e.g. net efficiency, effective efficiency and fractions (see e.g. Seckler *et al.,* 2003) aim to take into account real water losses. The level at which efficiency is measured is quite a relevant decision. Table 2 shows definitions of water productivity by crop, farm and basin level.

Table 2: Crop, farm and basin level water productivity.

Water productivity	Definitions
Crop water productivity	Crop water productivity or 'crops per drops' can be defined for different crops by comparing output per unit of water input[b]. 'Output' may either be in physical (usually measured in kg) or monetary terms. The amount of water depleted is usually limited to crop evapotranspiration (measured in m^3). Two examples: (i) Smith (2000): Yield (tc) / Transpiration (mm); (ii) Kassam and Smith (2001): Crop yield/water consumptively used in evapotranspiration. Here crop water productivity may be quantified in terms of wet or dry yield, nutritional value or economic return.
Farm productivity	The use of water in a farm as a system implies a different level of productivity compared to individual crop productivity as the considerations of other constraints (land, labour, machinery, financial, risk) may influence the optimal allocation of water in a crop mix. Water may be a constraining factor during some months and may not be scarce in others. Accordingly, a global systemic view of the farm implies a 'farm value' for the water that may be different to the value when considering a single crop.
Basin productivity	Takes into consideration beneficial depletion for multiple uses of water, including not only crop production but also uses by the non-agricultural sector, including the environment. Here, the problem lies in allocating the water among its multiple uses and users. Priority in use involves the value judgement of either the allocating agency or society at large and may be legally determined by water rights.

[b] *Some authors define 'total water productivity' by including also effective precipitation water, but in this paper we focus on irrigation productivity and we do not enter into the discussion about 'green' and 'blue' water.*

The use of physical measures of the output is easier to apply than economic definitions of 'value'. Young (2005) criticises the frequent use of 'value added' or 'total production' for measuring socio-economic benefits of water use, opposing OECD recommendations (see Bergmann and Boussard, 1976, p. 59). The concept of added value (or total value of production) may lead to misleading results since 'value added' comprises of several factor incomes (labour, capital etc.). We recommend that the choice of the economic indicator should be taken with precaution corresponding to the level of analysis (micro, meso, macro) and that, in general, the selected variable should be a value generated by the water use. When economic analyses are done at a meso- and macro-level the priority in use may include objectives of rural development or social or territorial equity that may be in conflict with maximizing economic efficiency and diverting water to the most productive location and sectors against more traditional crops and less favoured areas. Therefore the macro level concept of efficiency may consider social targets (such as more jobs per drop) that are not necessarily compatible with the pure economic definitions (more value per drop).

4. Other aspects related to water use efficiency in Mediterranean systems

An important issue in Mediterranean systems is the use of 'deficit irrigation', defined as the application of water below full crop-water requirements (i.e. evapotranspiration). This is a crucial strategy to maximize water productivity and efficiency. Generally, the farmer's adaptation to water supply limitations in water scarce regions is to cultivate crops with supplementary or deficit irrigation. This is a strategy that is expected to be used more frequently as in the future irrigated agriculture will take place under increasing water scarcity. Therefore, to maximize food production under soil and water constraints, irrigation management will focus more towards maximizing the production per unit of water consumed (water productivity), against the old strategy of intensive water use in some areas maintaining the rest under rain-fed conditions. Deficit irrigation is widely practiced over millions of hectares for a number of reasons - from inadequate network design to excessive irrigation expansion relative to catchment supply. A review can be seen Fereres and Soriano (2007) who conclude that there is a potential for improving water productivity of many field crops; there is sufficient information for defining the best deficit irrigation strategy for many conditions; and the level of irrigation supply under deficit irrigation should be relatively high in most cases. This is a strategy that increases the efficiency of the use of water by crops, but can be applied only to certain crops at some growth stages.

IV – Concluding remarks

> '*It is not the quantity of water applied to a crop, it is the quantity of intelligence applied which determines the result - there is more due to intelligence than water in every case.*'
>
> *Alfred Deakin 1890*

The paper shows that the term RUW is of utmost relevance to the irrigation sector as water scarcity and pressures on water are increasing. The term is multi-faceted, depending upon what decision level scale of water use we refer to. At a micro-level (household, farm and community level), the definition includes to maximize profit, water use efficiency and productivity; at a meso-level (institutions, river basin, infrastructure) to achieve an equitable and economic efficient allocation that does not increase the conflict level between competing uses; while at a macro-level (legal, national and international policy) sustainability and food security appear to be core aspects of RUW.

The single dimensional indicators (ratios) presented could potentially be used to aid measuring RUW. Still, it is important to carefully define the economic terms, as the measured 'value' depends on the decision-level or policy context in which the estimate is developed (Young, 2005, p 221). For example subsidies to production are an income for the farmer but an expense for the government. Additionally, most of the measures do not specify if they refer to depleted water or to diverted water. At crop and field-level much of the ‘apparent losses’ remain inside the hydrological system and do not represent losses at a meso level as most of the water returns to the basin. This consideration is an argument that supports the notion that rationality depends on the scale of analysis. In view of the diversity of definitions on WUE and WP indicators there seems to be a considerable confusion around the interaction between the hydrological cycle and these concepts, which again could produce confusing results for planners and policymakers involved in addressing issues of water scarcity. Even irrigation professionals use various terms interchangeably and without due regard to the clarity of their recommendations (Perry, 2007).

Summing up, for calculating productivity we recommend to use biomass, edible crops, dry matter, profit, water value in case of an economic target or job creation in the case of social objectives. The economic value should take into consideration the level of analysis, as the private farm measure of success (profit) is different from the global public measure of value (where e.g. taxes or subsidies are considered differently than from the private viewpoint).

References

Barbier E.B. (1990). Economics for sustainable production. In: R.T. Prinsley, ed. *Agroforestry for sustainable production*, p. 389-404. London, Common-wealth Science Council.

Bazza M. (2006). Overview of the history of water resources and irrigation management in the Near East Region. FAO Regional Office for the Near East. 1st IWA international Symposium on Water and Wastewater Technologies in Ancient Civilizations. http://www.fao.org/world/regional/rne/morelinks/Publications/English/HYSTORY-OF-WATER-RESOURCES.pdf

Berbel J., Mesa-Jurado M.A., Pistón J.M. (2011a) (forthcoming). Value of irrigation water in Guadalquivir basin (Spain) by residual value method. Water Resources Management DOI: 10.1007/s11269-010-9761-2

Berbel J., Martín-Ortega J., Pascual M. (2011b). A cost-effectiveness analysis of water-saving measures for Water Framework Directive: the case of the Guadalquivir River Basin in Southern Spain. *Water Resources Management*, Published online: 3 November 2010. DOI: 10.1007/S11269-010-9717-6.

Berbel J., Gutiérrez C. (2004). Sustainability of European Irrigated Agriculture under Water Framework Directive and Agenda 2000. Ed. European Commission. ISBN: 92-894-8005-X.

Bergmann H., Boussard J. (1976). Guide to the economic evaluation of irrigation projects. OECD, Paris. 247 p.

Biswas A. K. (2004). Integrated Water Resources Management: A Reassessment A Water Forum Contribution. *International Water Resources Association Water International*, Volume 29, Number 2, P. 248–256.

Blue Plan (2008). The Blue Plan s Sustainable Development Outlook for the Mediterranean. Sophia Antipolis, France: Plan Bleu

Clemmens A.J., Burt C.M. (1997). Accuracy of irrigation efficiency estimates. *J.Irrigation and Drainage Eng*. 123:443-453.

European Commission (2009). Adapting to climate change: Towards a European framework for action. WHITE PAPER. Brussels, 1.4.2009.

European Commission (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23rd October 2000 establishing a framework for Community action in the field of water policy. *Official Journal 22 December 2000* L 327/1, Brussels: European Commission.

FAO (2003). Review of World Water Resources by Country. *Water Reports 23*, Rome, 2003.

Gómez-Limón J.A., Berbel J., Arriaza M. (2007). MCDM farm system analysis for public management of irrigated agriculture. In: *Weintraub, A., BjorndaL, T., Epstein, R., Romero Y. C., (eds.), Handbook on Operations Research in Natural Resources in International Series in Operations Research and Management Science*,Ed. Kluwer, Nueva York; Páginas: 93-114; ISBN: 978-0-387-71814-9

Fereres E., Soriano M.A. (2007). Deficit irrigation for reducing agricultural water use — *J. Exp. Bot*. (2007) 58 (2): 147-159.doi: 10.1093/jxb/erl165

GWP-TAC (2000). Integrated Water Resources Management. Global Water Partnership – Technical Advisory Committee. TAC Background Papers No. 4. GWP, Stockholm, Sweden.

Hackett S. (1998). Environmental and Natural Resources Economics. published by M.E. Sharp, Armonk, NY.

Kassam A., Smith M. (2001). FAO Methodologies on Crop Water Use and Crop Water Productivity. Expert meeting on crop water productivity, Rome 3 - 5 December 2001, pp. 18.

Kahneman D., Tversky A., 1979. Prospect theory: An analysis of decisions under risk. *Econometrica* 47 (2): 263–291. doi:10.2307/1914185. http://jstor.org/stable/1914185.

Kijne J.W, Tuong TP, Bennett J, Bouman B.A.M., Oweis T. (2002). Ensuring food security via crop water productivity improvement. Background Paper 1. *In: Challenge Program for food and water.* Colombo (Sri Lanka): CGIAR-IWMI. 42 p.

Kundzewicz Z. W., Mata L. J. (n.y.). Concept paper on cross-cutting theme: WATER.

Malano H., Burton M., Makin I. (2004). Benchmarking Performance in the Irrigation and Drainage Sector: A tool for change. *Irrigation and Drainage*, 53: 119-133.

Mehta A.V., Yang S. (2008). Precipitation climatology over Mediterranean Basin from ten years of TRMM measurements. *Adv. Geosci.,* 17, 87-91, doi:10.5194/adgeo-17-87-2008.

Molden D. (1997). Accounting for water use and productivity. SWIM Paper 1. Colombo, Sri Lanka: International Irrigation Management Institute.

OECD 2001. Environmental Indicators for Agriculture. Methods and Results. Executive summary

Pearce D.W., Turner R.K. (1990). Economics of Natural Resources and the Environment. Published by Harvester Wheatsheaf.

Perry C. J. (1996). The IWMI water balance framework: A model for project level analysis. Research Report 5. Colombo Sri Lanka: International Irrigation Management

Perry C. (2007). Efficient irrigation; inefficient communication; Flawed recommendations. *Irrigation and Drainage*, 56: 367–378 (2007). Published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/ird.323

Rosegrant M.W. (1995). Dealing with water scarcity in the next century. International Food Policy Research Institute 2020 Brief 21, June 1995. http://ageconsearch.umn.edu/bitstream/16339/1/br21.pdf

Schoengold K., Zilberman D. (2004). Economics of Water Quality and Agriculture. Agricultural Water Quality and Water Use: Developing Indicators for Policy Analysis. Proceedings of an OECD Expert Meeting-Gyeongju, The Republic of Korea, October 2003.

Seckler D., Amarasinghe U., Molden D., de Silva R., Barker R. (1998). World Water Demand and Supply, 1990-2025: Scenarios and Issues. Research Report 19, International Water Management Institute, Colombo, Sri Lanka.

Seckler D., Molden D., Sakthivadivel R. (2003). The Concept of Efficiency in Water resources Management and Policy». Chapter 3 in *Water productivity in agriculture: limits and opportunities for improvement* edited by. International Water Management Institute, Colombo, Sri Lanka

Rockstrom J., Falkenmark M. (2000). Semi-arid crop production from a hydrological perspective: gap between potential and actual yields . *Crit. Rev. Plant Sci*. 19: 319-346**.**

Simon H. (1982). Models of Bounded Rationality . Volumes 1 and 2, MIT Press.

Smith M. (2000). Optimising crop production and crop water management under reduced water supply . 6th International micro-irrigation congress. SA National Council for Irrigation and Drainage. Cape Town, South Africa.

The World Bank (2007). Making the most of scarcity : accountability for better water management results in the Middle East and North Africa . MENA development report on water. DOI: 10.1596/978-0-8213-6925-8

UNEP/MAP-Plan Bleu (2009). State of the Environment and Development in the Mediterranean , UNEP/MAP-Plan Bleu, Athens, 2009.

Viets F.G. (1966). Increasing water use efficiency by soil management. In: *Plant environment and efficient water use*, ed. W.H.Pierre *et al.,* Madison, Wisconsin, USA: American Society of Agronomy.

Wallace J.S., Gregory P. (2002). Water resources and their use in food production systems. *Aqatic Sci* 64: 1-3

Wallence J.S. (2000). Increasing agriculture water use efficiency to meet future food production. *Agric Ecosystems Environment* 82: 105-119.

Willardson L.S., Allen R.G., Frederiksen H.D. (1994). Universal fractions for the elimination of irrigation efficiency. In: *Tech. Conf. of United States Committee on Irrig. and Drain.* (USCID), 13th, Denver, CO. 19–22 Oct. 1994. USCID, Denver, CO.

Young R.A. (2005). Determining the economic value of water: concepts and methods. Washington, DC. Resources for the Future. doi:10.1007/s10640-005-1956-2

Zoebl D. (2002). Crop water requirements revisited: The human dimensions of irrigation science and crop water management with special reference to the FAO Approach. *Agriculture and Human Values*. Doi: 10.1023/A:1019909704144

Zoebl D. (2006). Is water productivity a useful concept in agricultural water management? *Agricultural Water Management* 84, p265-273

Appendices

Annex 1 Abbreviation

CEA	Cost-effectiveness analysis
CBA	Cost benefit analysis
DEA	Data Envelopment Analysis
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GWP	Global Water Partnership
MAP	Mediterranean Action Plan
MCA	Multi-Criteria Analysis
MELIA	Mediterranean Dialogue on Integrated Water Management
OECD	Organisation for Economic Co-operation and Development
RUW	Rational Use of Water
SEMC	Southern and Eastern Mediterranean countries
SEMIDE	Système Euro-Méditerranéen d Information sur les savoir-faire dans le Domaine de l Eau
TAC	Technical Advisory Committee
UNEP	United Nations Environment Programme
WFD	EU Water Framework Directive
WP	Water productivity
WUE	Water use efficiency

Annex 2: Water demand, total and per sector, period 2000-2005.

Countries	Total demand (km^3/year)	Drinking water	Irrigation	Industry	Energy	Drinking water	Irrigation	Industry	Energy
		(km^3/year)				(%)			
Spain	37.070	5.300	24.160	1.440	6.170	14.3	65.2	3.9	16.6
France	34.960	6.200	4.100	3.380	21.280	17.7	11.7	9.7	60.9
Italy	41.982	7.940	20.136	7.986	5.919	18.9	48.0	19.0	14.1
Greece	7.800	1.250	6.300	0.130	0.120	16.0	80.8	1.7	1.5
Malta	0.058	0.031	0.024	0.003		53.4	41.4	5.2	
Cyprus	0.253	0.067	0.182	0.004		26.5	71.9	1.4	
Slovenia	0.894	0.187	0.007	0.080	0.620	20.9	0.8	8.9	69.4
Croatia	0.375	0.314	0.001	0.050	0.010	83.7	0.3	13.3	2.7
Bosnia-Herzegovina	0.930	0.230	0.600	0.100		24.7	64.5	10.8	
Montenegro	0.050	0.050				100.0			
Albania	1.700	0.460	1.050	0.190		27.1	61.8	11.2	
Turkey	40.100	6.000	30.100	4.000		15.0	75.1	10.0	
Syria	16.690	1.426	14.669	0.595		8.5	87.9	3.6	
Lebanon	1.400	0.450	0.940	0.010		32.1	67.1	0.7	
Israel	1.950	0.712	1.129	0.113		36.5	57.9	5.8	
PalestinianTerritories	0.280	0.125	0.155			44.6	55.4		
Egypt	70.430	4.760	58.800	2.200	4.670	6.8	83.5	3.1	6.6
Libya	4.260	0.600	3.540	0.120		14.1	83.1	2.8	
Tunisia	2.457	0.406	1.918	0.133		16.5	78.1	5.4	
Algeria	6.270	1.330	3.940	0.800	0.200	21.2	62.8	12.8	3.2
Morocco	9.488	0.855	8.475	0.158		9.0	89.3	1.7	
Total/Average									
North Shore	126.072	22.029	56.560	13.363	34.119	17.5	44.9	10.6	27.1
South and East Shore	153.325	16.664	123.666	8.129	4.870	10.9	80.7	5.3	3.2
Mediterranean	279.397	38.693	180.226	21.492	38.989	13.8	64.5	7.7	14.0
Ratio									
North Shore / Mediterranean	45%	57%	31%	62%	88%				
South and East Shore / Mediterranean	55%	43%	69%	38%	12%				

Source: State of the Environment and Development in the Mediterranean 2009 (UNEP/MAP-Plan Bleu, 2009).

Notes:
- Total water demand corresponds to the sum of water directly abstracted, including losses in transport and use, and the production of non-conventional water
- Drinking water demand refers to water directly abstracted and water issued from desalination of sea water and brackish water for supplying the households, public services, commercial establishments and deserved industries.
- Water demand for irrigation refers to water directly abstracted and non-conventional production (desalination, clean wastewater reuse, drainage, etc.) for irrigated agriculture production.
- Water demand for industry refers to water directly abstracted for the industries not deserved by the public drinking water network.
- Water demand for energy refers only to the thermal power plant cooling.

Sources: Plan Bleu, from national source

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(1) Jordan is often also considered part of the region though it is not bordering the Mediterranean sea.

(2) A list of abbreviation is given in Annex 1.

(3) See e.g. Wallence 2000; Rockstrom and Falkenmark 2000 (rain-fed) and Wallace and Gregory 2002 (irrigated agriculture).

(4) A draft version of this paper served as a starting point for the thematic group discussion on 'Rational Use of Water' in the MELIA-project in 2007. The authors want to thank Laila Mandi for inputs on a draft version of this paper.

(5) Norway and Switzerland have also committed to the WFD.

(6) www.fao.org

(7) SEMIDE thesaurus: http://www.semide.net/portal_thesaurus

(8) WFD Glossery: http://www.euwfd.com/html/glossary.html

(9) FAO: http://www.fao.org