Water International

Macro, meso, and micro-efficiencies and terminologies in water resources management: a look at urban and agricultural differences

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Published online: 13 Dec 2013.

To cite this article: Naim Haie & Andrew A. Keller (2014) Macro, meso, and micro-efficiencies and terminologies in water resources management: a look at urban and agricultural differences, Water International, 39:1, 35-48, DOI: 10.1080/02508060.2013.863588

To link to this article: http://dx.doi.org/10.1080/02508060.2013.863588
Macro, meso, and micro-efficiencies and terminologies in water resources management: a look at urban and agricultural differences

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(Received 3 March 2013; accepted 5 November 2013)

Efficiency of water resources is essential; just as important is the terminology that describes it. Paradoxes in terminologies used by various international institutions and professionals in the agricultural, urban and environmental domains are examined. Integrated terminologies are proposed, starting from flow-path types in water balance and expanded into the “macro, meso, and micro-efficiencies” (3ME) formulation. The 3ME is a systemic framework based on the principle of the conservation of mass, integrating water-flow paths of a water system, their beneficial and quality attributes (the usefulness criterion), climate, and two types of water totals. These terminologies, with nine examples for urban (three types) and agricultural areas (rainfed, surface, drip and sprinkler), are used to discuss the 3ME framework and possible flawed policy implications.

**Keywords:** water balance; irrigation; pollution; benefits; effective consumption; 3ME; efficiency

**Introduction**

Drivers of change in water resources are intensifying, and the management and governance of this vital resource are becoming increasingly complex in almost all regions of the world. As we analyze water systems (WS) for performance evaluation, maintenance or design, it is desirable and indeed inevitable to measure how this resource can be used in a better way. In this context, increasing system efficiency has become one of the most sought-after phenomena in recent years (e.g. IPCC, 2007; Department of Water Resources [DWR], 2012; European Commission [EC], 2011; Presidency of the Council of Ministers [PCM], 2005; UK Secretary of State for Environment & Food and Rural Affairs [SSEFRA], 2011; World Water Assessment Programme [WWAP], 2012) for at least three major reasons. First, humanity is increasingly being confronted with the fact that the resources of the earth, such as water, are indeed limited, even scarce. This consciousness is accelerating because of important changes in a series of drivers such as population, economics, climate, technology, land and governance (Biswas & Tortajada, 2009). The second reason is the limits on the earth’s ability to absorb humanity’s wastes, whether they are polluting substances in water or CO$_2$ in the atmosphere. Third, economies are in crisis and more needs to be achieved with fewer resources, i.e. going towards a decoupling of development from resource use and its environmental impacts (EC, 2011). Throughout the world, much political and economic capital is spent on efficiency, but with mixed results.

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For example, the Portuguese government has defined a 15-year programme to increase water efficiency in agricultural and urban areas (PCM, 2005) using a flawed model, classical efficiency (Seckler, Molden, & Sakthivadivel, 2003). By using a better model than classical efficiency, Haie, Pereira, and Machado (2008) and Haie, Machado, Pereira, and Keller (2011) showed that the anticipated efficiency increase programmed by the Portuguese authorities had already been achieved prior to their investments.

Measured or observed data is very important in any field. However, as the number of the descriptors and variables that influence a system increases, equally important, actually vital, is the understanding of the interrelations between those data. This is particularly the case in managing water resources because there are so many variables and actors that influence its proper execution, including those out of the “water box” (WWAP, 2009), making outcomes of management of water uncertain. For example, it is crucial to have information on how water gets distributed through a system (or among (sub)systems) and on the beneficial and quality attributes of those flow paths (Keys, Barron, & Lannerstad, 2012). Knowledge of their entering or leaving a WS is doubly important because of “the ‘political’ law of hydraulics: water flows upwards towards power” (Global Water Partnership [GWP], 2000).

When presenting the interrelations among different environmental, economic and societal descriptors, we must first have a clear and integrated terminology that conveys the same concepts for all the stakeholders. This first requirement is not met in water discourse because of fragmented stakeholder focuses and interests. For example, the phrase “water consumption” or “consumed water” is portrayed incorrectly in the glossaries and publications of UNESCO, FAO, WWAP, EEA, IWMI, IWA and ICID (see Table 1) (to be explained in the next section). After defining a proper terminology, we need to have an integrated and systemic framework to evaluate the performance of a WS, with all its assumptions and conditions well documented. There are many performance indicators, but none is more famous or at least conceptually important than efficiency. Recalling Stone (2002), “Efficiency is thus not a goal in itself. It is not something we want for its own sake, but rather because it helps us attain more of the things we value.” The word “efficiency” has been employed in many ways, such as economic efficiency, water-use efficiency, classical efficiency, effective efficiency, allocation efficiency and irrigation efficiency. Without trying to analyze each of them, two general points are important to mention here. The first is that there is a distinction between efficiency and productivity based on their units of measure. Efficiency is a percentage, but productivity has units such as kilograms of mass per litres of water. The second point is that the lack of a systems approach on the part of many of the efficiency indicators can sometimes bring about erroneous analyses and results. This has many sides, depending on which efficiency is

<table>
<thead>
<tr>
<th>Abbreviations and websites (All sites accessed 2012.)</th>
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<tbody>
<tr>
<td>ICID International Commission on Irrigation and Drainage [<a href="http://www.icid.org">http://www.icid.org</a>]</td>
</tr>
<tr>
<td>IPCC Intergovernmental Panel on Climate Change [<a href="http://www.ipcc.ch">http://www.ipcc.ch</a>]</td>
</tr>
<tr>
<td>IWA International Water Association [<a href="http://www.iwahq.org">http://www.iwahq.org</a>]</td>
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<tr>
<td>IWMI International Water Management Institute [<a href="http://www.iwmi.cgiar.org">http://www.iwmi.cgiar.org</a>]</td>
</tr>
<tr>
<td>WWAP World Water Assessment Programme [<a href="http://www.unesco.org/water/wwap">http://www.unesco.org/water/wwap</a>]</td>
</tr>
<tr>
<td>WWDR World Water Development Report (for this website, see WWAP)</td>
</tr>
</tbody>
</table>

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being evaluated, some of which were discussed by Haie and Keller (2008) and more recently by Haie and Keller (2012) in developing their “macro, meso, and micro-efficiencies” (3ME) framework.

To clarify some of the above issues, this paper presents an integrated terminology based on the conservation of mass and its systemic attributes; explains in some detail the inconsistencies between urban and agricultural ways of looking at water-balance flow paths; explains a set of new composite efficiency indicators; and presents a few examples that show the impacts of urban and agricultural systems using the new terminology and indicators.

A look at the water-consumption paradox

Background

To analyze the inconsistencies between urban and agricultural water consumption, let us remember that the important water-flow quantities for the two are different. For urban areas, the emphasis is on having a clean source that can supply reliable and safe water; hence water abstraction (VA; see Annex, Table A1 for definitions) is vital. For agricultural systems, the crucial water-flow path is evapotranspiration (ET), as it is linearly proportional to yield (Howell, 1990; Steduto, Hsiao, & Fereres, 2007), which is the purpose of irrigation systems. The treatment of pollution produced out of these two domains is also different. In agriculture, the focus is on salt, which some irrigation systems try to handle. In urban areas, pollution control has become one of the main foci of urban experts. These are particularly true as environmentalists, chemists, ecologists, biologists, etc. have gained a much stronger voice in relation to water problems. In almost all cases (agriculture or urban), the study of pollution proceeds separately from analysis of the quantity paths, particularly ET and VA.

However, despite these subtle but significant underlying differences, the two camps keep using the word “consume” as before. This means that water consumption mostly means ET for the agricultural community and VA (or its sub-parts, such as household water uses) for the urban experts. Using this common term, the agricultural community has mostly maintained its quantity-based terminology in proposing frameworks such as water accounting, water productivity, efficiencies and fractions, while explicitly excluding quality (DWR, 2012; Frederiksen & Allen, 2011; Lankford, 2012; Molden & Sakthivadivel, 1999; Perry, 2007). As the water resources crisis grew, mostly urban and environmental experts went on to develop big and crucial reports, such as the WWDR reports (e.g. WWAP 2012) and the water parts of IPPC reports (e.g. IPCC 2007), but using the common word that resulted in the propagation of the differences.

One factor that contributed significantly to the continued use of the word “consume” in both domains is the apparent ease of communication with decision makers, with the public in general, and among various researchers of increasing diversity. Everybody uses the word in connection with phrases such as energy consumption, food consumption, consumer, etc. But contrary to these types of consumption, very few notice that water consumption is very different from the consumption of food or energy. Even within the wide world of water, experts use the word in relation to different removal processes. For example, urban water experts employ the word “consume” mostly knowing that the resulting pollution effectively puts the water in such a changed state that it is equivalent to its removal from the WS. Agricultural experts mostly equate water consumption to ET, which is physically removed from the system. Although in both situations the water cannot be reused, there are
fundamental differences between the two “removal” processes. To make this clear, we need only look at our daily lives, as the following paragraph explains.

Let us consider simple examples to appreciate some of the dissimilarity between using water and consuming water, to give us a background for the paradoxes and definitions set forth later. Everybody should know the fundamental difference between boiling one litre of water in a kettle (letting perhaps a quarter of it evaporate), and using one litre of water to wash a dirty dish. The first leaves us with only three-quarters of the water for reuse (for example, making tea). So we used one litre of water but we had a consumption \( C \) of one-quarter, meaning that one-quarter is not physically available for further reuse. Also, the \( C \) process caused the three-quarters of a litre of water left behind to contain a higher concentration of minerals and some of the minerals to stick to the walls of the kettle. This problem, a direct consequence of \( C \), needs water and other resources to clean up. The second process, washing a dish, uses the same litre of water for a different purpose, and at the end most of the water, if not all, is available for reuse, though with a quality lower than the original litre. The water cannot be used for the same purpose (or any other purpose that requires better water quality) but probably can be used, for example, to irrigate a flower pot. Or perhaps this amount of water with lower quality can clean (close to the same level as the first cleaning) a dish smaller than the first one. Whatever the path of reuse, the original one litre of water was used, and thereby some of the water was effectively consumed, meaning that the available water may not be reused for the same purpose (i.e. washing a dish) or any other purpose that requires better water quality (e.g. babies drinking it). Consequently, the amount of water that was effectively consumed changes according to the nature of the reuse and our preferences: it equals 100% if the reuse is intended for a baby, perhaps 60% if intended for another dish, or perhaps 5% for a flower pot. Willardson, Allen, and Frederiksen (1994) hinted at such a condition and called it “true” consumption, but they immediately continued with quantity and particularly ET, because the focus of their paper was agricultural water use. Now let us look at some of the publications that confuse quantity and quality and flow paths in relation to the word “consume”.

A survey of the publications

The authors have inspected publications of the UN (FAO, UNESCO, WWAP) and of various regions (DWR, USA; EEA, EU), organizations (ICID, IWA, IWMI) and authors. This is a limited and selected, but representative, list. It should be mentioned that finding inconsistencies in their publications and definitions does not by any means diminish their fundamental, necessary and useful work.

In the FAO (Aquastat) glossary, available at its website (Table 1), there are definitions for “water consumption”, “consumed water”, “consumptive water use”, and “crop consumptive water use”. To have four quantity definitions for the word “consume” is an indication of lack of confidence as to the nature of the word itself, but also of uncertainty in a comprehensive terminology. These impressions are reinforced as the FAO goes on to state that these terms are “not to be confused with water withdrawal”, by itself showing the confusion in their terminology. Furthermore, these definitions use the words “significantly” and “substantial” in relation to pollution and water quality because the FAO doesn’t treat quality in degrees but as binary – either there is consumption due to contamination or not – which is not a proper presentation of reality. What is said in the Background section shows that the FAO’s glossary and publications have difficulty in realizing that water-flow paths and their attributes (the usefulness criterion, to be explained in the next section) should be integrated through water balance.
In the UNESCO definition (International Glossary of Hydrology), “consumptive use” is mainly equated to ET (or evaporation and transpiration) and then expanded to “a loss of the original water supplied”, which seems to be a flawed perspective. Are water uses in households and industries considered consumptive use? For UNESCO, the answer seems to be yes. Is polluted water resulting from an urban or agricultural area considered consumptive use? The answer is inconsistent. This lack of clarity probably extends to various programmes, such as WWAP, as explained next.

For example, the last WWAP (2012) report does not even define the important term “water consumption” in its 10-page glossary. A keen reader can find many instances of confusion in using different interpretations for the term; here let us only note four entries from the glossary section and the body of the report:

- In defining “withdrawal”, the report notes that “The water that is not consumed is subsequently returned to the environment after use, but the quality of the returned water may not be the same as when it was removed.” This seems to portray (by negation) a quantity-based definition of water consumption (e.g. ET), ignoring water quality.
- Another entry in the glossary is “non-consumptive production process”, which is defined as “production processes that may use but do not consume water”, which is circular reasoning and hence a logical fallacy. But it distinguishes between water use and water consumption.
- “Low-flow appliance” is defined as “an appliance that is designed to reduce water consumption without compromising performance of the appliance”. Examples given of such low-water-consumption equipment are “low-flush tank toilets and low-flow or waterless urinals”. This urban and environment-based definition of water consumption seems to oppose the definition given above for “withdrawal”.
- It should be added that throughout the report, pollution is sometimes considered as contributing to consumption and sometimes not. This confusion even happens within the same chapter (e.g. pp. 54–60).

The EEA’s glossary (Environmental Terminology and Discovery Service) also has various definitions that involve the word “consume”, such as “water consumption”. This includes the definition of another entry, “consumptive use of water”, which is a quantity-based definition. The EEA goes on to also include any use of water that results in its becoming “unfit for any subsequent use”. This is presumably polluted water, but EEA publications do not include pollution in dealing with water consumption and do not clarify the difference between water use and consumption (e.g. EEA 2012). Again the confusion in dealing with flow paths is clear: the EEA’s definitions mix up at least four types of water flows (described in the next section of this paper).

The case of DWR (2012) is of interest because of the severe water problems in California. In this report to the state legislature, two basic terms are defined: “crop consumptive use” and “consumptive use” which includes “water that is unavailable for reuse ... by contamination”. The first is defined as beneficial ET minus beneficial precipitation, and it is used to define one of the methods (efficiencies). This attempt makes the method equal to the flawed classical efficiency, which the DWR should have avoided. (Actually, it is not clear why the authors of the report changed the name of a well-known efficiency expression.) The second term is not used in the report, i.e. contamination is bypassed, with no explanation of the reason for including the second term in the glossary. In both cases, there are incomplete and fragmented considerations of water paths, qualities and beneficial attributes in the context of water balance.
The ICID does not have a freely available glossary, but its definition (ICID-MTD: Multilingual Technical Dictionary 2010) of consumptive water use is only quantity-based. Besides, water consumption and ET are typically defined and used interchangeably, the assumption being that ET constitutes most of the consumed water in an irrigation setting. On the other hand, in many of its documents the IWA, a mostly urban-focused organization about water, utilizes the word “consume” and its derivatives to include water that is used, contaminated, and then returned to the system (in contrast to water that is not returned). The IWMI is mostly focused on irrigation, and sometimes recognizes the need to include pollution (besides quantity) in the definition of water consumption, but somehow fails to apply it, or simply considers a quantity-based leaching requirement for salt.

Now let us briefly examine one flawed attempt that is introduced to partly compensate for terminology paradoxes. In the irrigation community, authors such as Willardson et al. (1994), Allen, Clemmens, and Willardson (2005), Perry (2007), Jensen (2007), Perry, Steduto, Allen, and Burt (2009), and Frederiksen and Allen (2011) promote the use of fractions for managing water. Fractions are defined as the ratio of a flow over a water total of a WS, such as ET divided by VA (abstracted/applied water), which we call ET fraction (ETF). Fractions are about water quantity, without any consideration for quality. In presenting them, some of these authors and others (such as DWR, 2012; Ward & Pulido-Velazquez, 2008) promote terminology mismatches. For example, they utilize the phrase “consumed fraction” (CF) (or “consumptive fraction”) in defining the fraction of the total water use that is ET. Sometimes other non-reusable outflows are added to ET, but the mismatch continues. The same author may even present different definitions of CF or water consumption in different papers. Anyhow, they define consumed water or consumptive use as ET plus other flows, such as water entering a salt sink or contaminated water, hence making the proper term ETF and not CF. Besides, fractions are fragmented and, like classical efficiency, promote a flawed approach (Haie, 2008).

It should be mentioned that water consumption is also beneficial by degrees. For example, crop ET is beneficial (ETb), while returned flow (e.g. RP) depends on the degree of pollution, as illustrated in the previous subsection. We even have ET that is not beneficial. Hence, flow paths, quality and beneficial aspects of water are crucial factors in defining a proper terminology. In a water-scarce region, even beneficial consumption should be decreased. For instance, how much to decrease C (a critical condition ignored by the proponents of fractions) also depends on the values of the society, i.e. it is value-ridden, and hence the growing court battles. Consequently, the fundamental question is how to integrate the above three factors into a coherent framework. The terminology proposed in this paper solves the paradoxes, and the new 3ME framework comprehensively and systemically uses this terminology to promote sustainable development.

An integrated terminology based on water balance
To use the law of conservation of mass, i.e. water balance, we need to define a water system. It is a system characterized by its water-flow path types and their attributes. These are defined as quality and beneficial aspects, which are incorporated into a “usefulness criterion” (Haie & Keller, 2012). These attributes and the boundaries of a WS, such as a city, farm or basin, are set according to stakeholder preferences. In general, the boundaries are easy to define, which leads to setting their flow paths, a more difficult task. The same authors have defined a set of flow-path types within the context of water balance which seems to be general enough for most WSs, such as the one shown in Figure 1. A caution: one thing common in many approaches and publications is the use of the phrase “water
balance”. However, none of them employ this fundamental law comprehensively to derive their indicators; they just utilize a few of the terms of the water balance (such as ET and VA) while ignoring other flows. This confuses the discourse by trying to show that their approach is systemic and based on a fundamental principle, but a keen reader can see otherwise.

The different flow paths have the same unit of measurement (such as millimetre). They are defined in the next subsection and summarized in Table A1.

**Usefulness criterion and water balance variables**

The two attributes of flow paths mentioned in the previous sections set up a usefulness criterion (Haie & Keller, 2012), as defined in Equations (1).

\[
\begin{align*}
X_b &= W_{bX} \times X \\
X_q &= W_{qX} \times X \\
X_s &= W_{sX} \times X \\
W_{sX} &= W_{bX} \times W_{qX}
\end{align*}
\]  

(1)

\(X\) can be any flow, such as VA or RF (please refer to Figure 1 and Table A1). \(W\) is the corresponding weight on a flow path for its beneficial (b), quality (q) or useful (s) attribute. For example, if \(W_{bX}\) is 0.8 and \(W_{qX}\) is 0.9, then the useful part of \(X\) is 0.72 of its value, which of course is less than 0.8 (e.g. the relative economic weight of the water along path \(X\)). \(W_{bX}\) and \(W_{qX}\) are taken as independent, meaning that, for example, the beneficial weights are set without considering the quality weights. Or, putting it in another way, \(W_{bX}\) values are set by assuming that \(W_{qX}\) values are equal to one. Hence, if the water is polluted \((W_{qX}\) less than one), then the useful weight, \(W_{sX}\), is less than 0.8.

In relation to water variables, we can readily designate two basic flow paths and two combined ones: evapotranspiration (ET), non-reusable water (NR), consumption (C) and effective consumption (EC). ET is an outflow from a WS that is generally calculated via an equation such as Penman and Monteith’s. It is through ET, for example, that various climate factors such as temperature enter into the efficiency indicators and equations. NR is the other outflow that is non-reusable (no double counting), including for example evaporation, “virtual water” embodied in various products manufactured within the system under analysis, and other processes. The combination of ET and NR is called consumption (C), and it is the total quantity of outflow that is not available for reuse.
However, one should be careful in applying the usefulness criterion in calculating useful consumption (UC) for the MicroES (defined in the next section) of urban areas. Here, it should be remembered that there are internal processes, such as the use of water by the population and its subsequent pollution, that should be included in NRs. On the other hand, EC is the total amount of water that is not available for further reuse for the purposes set forth by society. EC includes C but also beneficial and quality attributes, hence conveying the degree to which a WS makes water non-reusable.

Two other generic outflows are set in the water balance (Figure 1): return flow (RF) and potential return (RP), together called return (R). RF is the water returned from a WS to the source of the abstracted water. RP is the water returned from a WS to the environment outside of it (not returned to its source of abstraction), which could be one or more of the following: runoff; deep percolation; seepage; spills; leaching; and eventually other outflows. It should be noted that the question of what portion of a flow is actually recoverable depends on the financial, technical and cultural circumstances of the locality.

OS (other sources) is the inflow from sources other than the main source. If the main source is a river, as shown in Figure 1, OS could be water from groundwater, from another basin, or from other inflows. The remaining basic variables are self-explanatory and are defined in Table A1. Obviously, not every WS has all the flow paths schematized in Figure 1, but assigning zero to a flow type makes the process transparent with responsibility. The change in storage of a WS is mostly zero for the period of analysis, but if not, a combination of R and OS describes the required change in storage. Finally, combining the basic flows and applying the usefulness criterion to system flow paths give us an expanded terminology, as defined in the Annex, Table A2. For example, it shows that the total inflow (I) into a WS is the sum of VA, PP and OS (as also shown in Figure 1), and if we apply the usefulness criterion to I, then we get the total useful inflow (UI). These variables and attributes having been defined, they are employed in the next section to briefly explain the efficiency indicators. To understand the logic and objective principles and procedures used in their development, the reader should refer to Haie and Keller (2012).

**Sustainable efficiency (sefficiency)**

Let us make explicit a number of desirable features of an efficiency formulation of a WS. It should include: water quantity and quality; benefit differentiation for our diverse activities; purposeful distribution of water resources in nature; different levels of analysis; stakeholder involvement; and climate descriptors such as temperature and precipitation. All these are part of the 3ME (or “sefficiency”) framework that is formally developed in Haie and Keller (2012) and presented below in Equation (2) for ease of reference. Please note that the subscript S (defined in connection with Equation (1)) applies to all variables within the brackets.

\[
\text{MacroES}_S = \frac{ET + NR + i(VD + RP)}{VU + OS + PP - c(VD + RP)}_S \quad ; \quad i, c = 0 \text{ or } 1, \quad i + c = 1
\]

\[
\text{MesoES}_S = \frac{ET + NR + i(RF + RP)}{VA + OS + PP - c(RF + RP)}_S
\]

\[
\text{MicroES}_S = \frac{ET + NR}{VA + OS + PP}_S
\]
The two indices $i$ (inflow models) and $c$ (consumptive models) correspond to two water totals: useful inflow and effective consumption. Each index is either zero or one, with their sum equal to one. The appearance of one of these before MesoE or MacroE shows the type of indicator. For example, iMesoE means meso-efficiency calculated as an inflow model ($i = 1$, $c = 0$). The necessary minimum conditions natural to the systemic formulation are that in applying Equation (2), useful outflow must be less than useful inflow and useful consumption must be less than effective consumption. MacroE$_S$ gives the impact of a WS on the basin (the main source of water), while MicroE$_S$ is about the efficiency of a WS itself (i.e. without considering its returns). MesoE$_S$ is between the other two in that it includes return flows in its calculation, i.e. considering the impact of the system on the downstream users, including nature.

Because of its importance, let us rephrase what was already said. It should be noted that consumption (C) is the portion of outflow from a WS that does not return, e.g. to the river basin for further reuse. In the 3ME framework, this quantity-based definition is extended to include beneficial and quality considerations by employing the usefulness criterion. Useful consumption (UC) is consumption with the usefulness criterion applied to it, so that UC \( \leq \) C. The generalization goes further and designates a total value called effective consumption (EC), which is the portion of outflow from a WS that is not available for reuse for the intended purposes. For example, water flowing into a WS (e.g. VA) gets degraded as it leaves the system (e.g. RF), causing a decrease in its effective and real availability for reuse. In other words, any increase in pollution adds to the effective consumption of a WS (UC \( \leq \) EC).

Impacts of urban and agricultural water usage

Nine hypothetical examples are briefly discussed in this section using the terminology and the indicators explained in the previous sections. The numbers presented for different examples show the general tendencies based on real data with an agroclimatic and urban setting, having in mind that they can potentially exhibit wide ranges of values. However, the purpose of this exposition is to show the usefulness of a common terminology along with a systemic performance framework (i.e. 3ME) that can explicitly present some of the inherent relations between urban and agricultural water systems. In doing so, ET$_S$ (important to agriculture), R$_S$ (important to urban systems), MicroE$_S$, cMesoE$_S$ and iMesoE$_S$ are analyzed, with the assumption that the UI for all the examples is the same.

In other words, average representative values for ET$_S$ and R$_S$ under drier conditions are assumed and then normalized to vary from zero to UI. UI itself is assumed to be less than 100 (e.g. 85), in order to fit the examples into one readable figure. Such normalization does not affect efficiencies or the relative values of ET$_S$ and R$_S$ for each case. This is to say that each example by itself shows an expected situation.

Six of the examples focus on agriculture (including five irrigation methods), and the other three show different urban cases, as follows (see also Figure 2):

- **RFA**: rainfed agriculture (no irrigation)
- **SIT**: traditional surface irrigation
- **SIP**: precision (levelled, surged, etc.) surface irrigation
- **DIM**: marketed drip irrigation (“marketed” means performing as promoted or advertised)
- **DIR**: real drip irrigation (this constitutes most field drip systems)
- **SPI**: sprinkler irrigation
There are many ways of looking at the data presented in Figure 2. For example, transferring water from irrigated agriculture to urban areas (UW0) seems to be good for populations and industries because MicroE increases. But both inflow and consumptive meso-level efficiencies (iMesoE and cMesoE) go down very much. This means that useful outflow per unit of useful inflow decreases, and useful consumption per unit of effective consumption decreases. In other words, transferring water from agriculture to an urban area proves to be good for the urban area itself but not good for the downstream users.

However, a WWTP (with its associated costs) can be added to UW0 to give UW1, which increases both meso-efficiencies. Although cMesoE is greatly increased (almost tripled), it is still lower than in agriculture. However, the iMesoE of UW1 goes up considerably. If conservation measures like LFTs are used and the leaks in urban water systems are reduced (UW2), the three micro- and meso-efficiencies go up, with MicroE and iMesoE attaining maximum values in water systems.

It is not the purpose of this paper to design systems, but a quick comparison shows other potential relations. Suppose the stakeholders decide that any efficiency difference within 2 pp (percentage points) is not significant, and as a result two efficiencies this close (e.g. before and after intervention) can be considered practically the same and be labelled “equal”. If the difference between efficiencies is closer to 5 pp, the greater is labelled “slightly higher”. Now, if a WS is working under SIP and the intention is to change to DIR, we know that under the conditions of Figure 2, cMesoE and iMesoE will be slightly higher, but MicroE increases more than 5 pp. So the question arises whether the efficiency changes justify the interventions (whatever they are). But if our original system runs under SPI (instead of SIP), the change to DIR gives us only slightly higher efficiencies, i.e. cMesoE, iMesoE and MicroE only increase between 2 pp and 5 pp.
In practice, the thresholds mentioned above should be set according to the specific objectives of a society, which are, in turn, set by the stakeholders involved within a political process. Social, economic and environmental equity and justice influence these thresholds and the weights on flow paths and, consequently, the final decisions. However, whatever the values chosen, these are now explicit, transparent at some level, and based on science, for any interested party to see and to evaluate.

Let us look at other results taken from Figure 2. For example, the iMeso$E_S$ for urban areas with WWTP (UW1) is equal to that for sprinkler irrigation systems (SPI). This could have an interesting impact on decisions to divert water from SPI systems to urban areas under the pretext that UW1 is more efficient (Micro$E_S$), and would leave nature with relatively more useful water, because the end result might prove otherwise. Among many interpretations from Figure 2, let us look at another example: the Micro$E_S$ of SIP is equal to that of RFA (within 2 pp), meaning that sometimes technology does not produce higher local efficiency. As a final point, it should be mentioned that in the above discussions, there is no mention of DIM although it shows the best efficiencies. This is because the decisions to invest under DIM are most likely to be made based on perceptions of drip irrigation that in reality are not realized.

**Conclusions**

There are two issues that promote goodness in a water system, if done correctly: efficiency and equity (or justice). In this paper, the focus is on the first one as a performance indicator and in relation to water resources, i.e. on the question of how well the flows of a system are used. To do this, an integrated and systemic terminology was proposed that different stakeholders from various sectors and institutions can use in a common language in order to make proper decisions. This paper shows that if each actor (from urban, agricultural and environmental experts to other decision makers) has its own language, descriptors and interpretations, then there is a tendency towards paradoxes and mismanagement. Critical to resolving differences is to properly distinguish, in the context of water balance and social purposes, between the portions of the used water that are consumption and effective consumption. The latter is important because it explicitly integrates water quantity with the two fundamental attributes of quality and benefits, which in turn are parts of the new performance indicator, 3ME. These efficiencies can inform us as to the current conditions of a WS and the future scenarios for its development.

Using 3ME in conjunction with a number of examples, it was shown that thinking in terms of the framework presented in this paper, which consists of a proper terminology, the concept of the usefulness criterion, and the 3ME formulation, possible interesting outcomes can emerge. These are different comparative results between urban, rainfed and various methods of irrigated agriculture. For example, it was shown that although the consumption of water used in urban areas is low relative to agriculture (in line with general discourse), the cMeso$E_S$ of urban systems is lower than for agriculture (opposite to general discourse). Also, the difference in cMeso$E_S$ between real drip irrigation and traditional surface irrigation methods is 5 pp or less. Their iMeso$E_S$ values are basically the same, but their Micro$E_S$ values are very different (this being the focus of general discourse). These and other results convey the possibility of flawed interpretations in our decision making.

It should be mentioned that the reader might not agree with the values shown in Figure 2 for each example. This is understandable. But at the same time it should be
realized that the figure is for the demonstration of the great potential of the logical and integrated concepts put forth in this paper.

Lastly, it should be mentioned that change is difficult because of the forces of traditions and advocacies. With regard to the terminology proposed in this paper, it will be difficult for urban experts to fine-tune the employment of the word “consumption” and adopt other words, such as “usage”. For the irrigated-agriculture community, it will be hard to realize, and more importantly, to treat the word “consumption” as having degrees rather than only two possibilities (binary). For environmental analysts, particularly those in fields of knowledge such as biology, chemistry and sociology, probably all this will be difficult because their focus is mostly on other specific issues, such as fish, mercury and energy, important as they are. But if we go beyond the common forces that shape most of our decisions, the change will benefit us all.

Acknowledgements
The authors would like to thank the Civil Engineering Department of the University of Minho and the Portuguese Foundation for Science and Technology (FCT) for their help in making the production of this paper possible. The comments of two experts, one at the UN WWAP and the other at the FAO, who agreed to review the first draft of this paper were much appreciated and we are grateful for the comments of the two anonymous reviewers. We also extend our thanks to the four anonymous internal reviewers and Deputy Editor-in-Chief of Water International.

Note
1. With respect to the UNESCO glossaries, the “main” glossary ignores pollution. There is another glossary: WMO & UNESCO (2012), which is also accessible via the UNESCO website. Here, at the end of the definition of “consumptive use”, it adds “the degraded effluent which cannot be reused directly without appropriate treatment”. This brings water quality into the term. But in this glossary, “drinking water” is also labelled as a consumptive type.

References


### Annex. Terminology summary

#### Table A1. Basic flow paths of a WS.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET</td>
<td>Evapotranspiration</td>
</tr>
<tr>
<td>NR</td>
<td>Non-reusable</td>
</tr>
<tr>
<td>OS</td>
<td>Water from other sources</td>
</tr>
<tr>
<td>PP</td>
<td>Total precipitation</td>
</tr>
<tr>
<td>RF</td>
<td>Return flow</td>
</tr>
<tr>
<td>RP</td>
<td>Potential return (does not return to the main source)</td>
</tr>
<tr>
<td>VA</td>
<td>Abstracted/applied water from the main source</td>
</tr>
<tr>
<td>VD</td>
<td>Volume of water downstream after RF in the main source</td>
</tr>
<tr>
<td>VU</td>
<td>Volume of water upstream before abstraction in the main source</td>
</tr>
<tr>
<td>V1</td>
<td>Volume of water at Section 1 (VU or VA)</td>
</tr>
<tr>
<td>V2</td>
<td>Volume of water at Section 2 (VD or RF)</td>
</tr>
</tbody>
</table>

#### Table A2. Combining basic flow paths and applying the usefulness criterion.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Expression</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>V1 + OS + PP</td>
<td>Inflow</td>
</tr>
<tr>
<td>R</td>
<td>V2 + RP</td>
<td>Return</td>
</tr>
<tr>
<td>C</td>
<td>ET + NR</td>
<td>Consumption</td>
</tr>
<tr>
<td>O</td>
<td>C + R</td>
<td>Outflow</td>
</tr>
<tr>
<td>UI</td>
<td>Is</td>
<td>Useful inflow</td>
</tr>
<tr>
<td>UR</td>
<td>Rs</td>
<td>Useful return</td>
</tr>
<tr>
<td>UC</td>
<td>Cs</td>
<td>Useful consumption</td>
</tr>
<tr>
<td>UO</td>
<td>Os</td>
<td>Useful outflow</td>
</tr>
<tr>
<td>EC</td>
<td>(I - R)s</td>
<td>Effective consumption</td>
</tr>
</tbody>
</table>