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Sustainable Efficiency (Sefficiency) of Water Use Systems Amidst Environmental Impacts

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Abstract - Water use systems (WUSs), such as, urban areas and irrigated agriculture, are under increasing pressure due to various uncertain drivers, such as, global warming and population increase. Because of these phenomena, water scarcity and pollution are increasing causing severe economic, environmental and social damages. Consequently, water management and design (WMD) must focus on comprehensive performance of WUSs by integrating three pillars: water quantity, quality and benefits. These are the foundations of a new framework called Sefficiency, which incorporates the three dimensions of sustainability: environmental, economic and social. Sefficiency indicators have three levels Macro, Meso and Micro (3ME, in %), which make the trade-offs between pillars, dimensions and levels transparent. The crucial distinction between water use and water consumption produces both IN / OUT Sefficiency indicators, crucial for comprehensive and systemic analyses. The logical proof of Sefficiency is objective based on the water balance principle for any WUS under analysis. This universal law guarantees the robustness of the results of 3ME by defining nine Water Flow path Types (WFT). The fact that they are fixed and hydrologically unambiguous promotes a powerful and explicit enabler for active and effective involvement of various types of stakeholders. Usefulness Criterion for each WFT and/or Water Flow Paths is the multiplicative impact of both water quality and beneficial weights. Hence, Sefficiency is the ratio of useful outflow to its corresponding total useful flow, which can reveal the complexities and non-linearities in WMD. For this paper, after presenting a summary of Sefficiency, a simple agricultural example is explained, showing some of the possibilities of Sefficiency. For example, the use of technology as a positive change agent may, under some circumstances, prove to be harmful. This is particularly so if the system has more than one objective, such as, food production and groundwater recharge or pollution control.

***Keywords*:** sustainable efficiency, Sefficiency; water management; trade-off; water balance; pollution; benefits; water use and water consumption; Multi-level water reallocation

1. Introduction

About 90% of the global economic activity dependent on water [1]. Because of various drivers of change, efficiency of water use systems (WUSs) has become a central tool for adaptation purposes. In advancing sustainable water efficiency, three pillar must be integrated: water quantity, quality and benefits. These are also embodied in the UN definition of water security [2]. They are depicted in Figure 1.

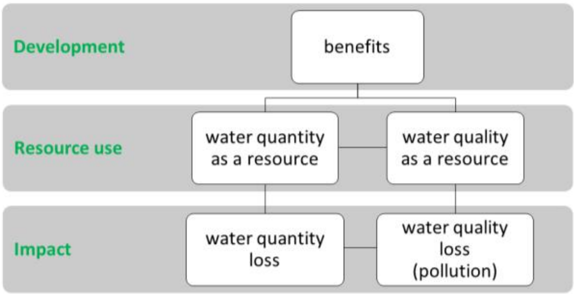

Fig. 1: Water quantity, quality and benefits in Water Security [3].

Also emphasizing the significance of Figure 1 is the benefits of food production, which is a focal point of this paper. They are achieved in an agricultural sector [4] that “is still causing very significant environmental and economic damage, for instance inefficient use of scarce water resources or pollution requiring expensive treatment. This reduces their availability for a range of economic activities thereby eroding the future growth opportunities of several EU regions.”

2. Sefficiency Methodology

Most of what follows is from two papers [3] and [5]. Figure 2 presents the Water Flow path Types (WFTs) that are used to define the terminology presented in Tables 1 and 2 (with Usefulness Criterion of Eq. (3)) upon which the indicators of Eq. (1) can be developed.

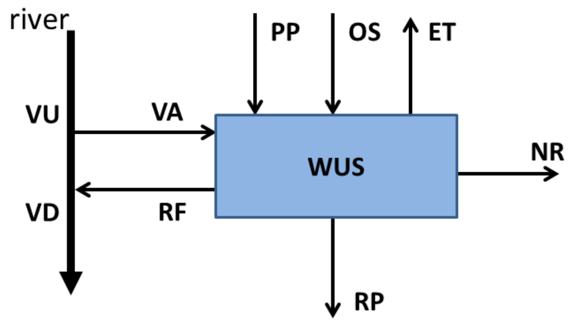

Fig. 2: A typical schematic for a Water Use System (WUS).

Table 1: Fixed Water Flow path Types (WFTs) of a WUS.

Variable	Description
ET	Evapotranspiration
NR	Non-Reusable
OS	Water from Other Sources
PP	Total Precipitation
RF	Return Flow
RP	Potential Return (does not return to the main source)
VA	Abstracted / Applied water from the main source
VD	Volume of water Downstream after RF in the main source
VU	Volume of water Upstream before abstraction in the main source
V1	Volume of water at section 1 (VU or VA)
V2	Volume of water at section 2 (VD or RF)

Table 2: Combining basic WFTs and applying Usefulness Criterion, Eq. (2).

Symbol	Expression	Description
I	V1 + OS + PP	Inflow
R	V2 + RP	Return
C	ET + NR	Consumption
O	C + R	Outflow
UI	I_S	Useful Inflow
UR	R_S	Useful Return
UC	C_S	Useful Consumption
UO	O_S	Useful Outflow
EC	$(I – R)_S$	Effective Consumption

In Table 2, it can be noted that Consumption (C) is the portion of Outflow (O) from a WUS that does not return to the basin for further reuse, meaning that ET is a water consumption but VA is a water use. These two types of water have different treatment and analysis and should not be confused.

$$MacroE_S = \left[\frac{ET + NR + i\,(VD + RP)}{VU + OS + PP - c\,(VD + RP)}\right]_S \; ; \; i + c = 1 \; with \; i, c \; \in \; \{0,1\}$$

$$MesoE_S = \left[\frac{ET + NR + i\,(RF + RP)}{VA + OS + PP - c\,(RF + RP)}\right]_S \quad (1)$$

$$MicroE_S = \left(\frac{ET + NR}{VA + OS + PP}\right)_S$$

In Eq. (1), “i” and “c” stand for inflow and consumptive models. For example, $iMesoE_S$ is an inflow Sefficiency indicator (i.e., i=1) which gives the percentage of total useful inflow that is useful outflow. While $cMesoE_S$ (i.e., c=1) provides the percentage of effective consumption that is useful consumption. The useful dimension of a water flow path X (X_s) is derived by using two weights:

$$\begin{aligned} X_b &= W_{bX} * X \\ X_q &= W_{qX} * X \\ X_s &= W_{sX} * X \\ W_{sX} &= W_{bX} * W_{qX} \end{aligned} \quad (2)$$

With W_{bX} being the beneficial weight on the water flow path X, W_{qX} its quality weight and W_{sX} the usefulness weight. All the weights vary between zero and one with the latter giving the best condition. Also, the Water Flow Paths (WFPs) and their weights are set within a clearly defined time frame. If all the quality weights are set to one, then a quantity based Sefficiency is given and the analyses is carried out without water pollution consideration. Such quantitative studies, although popular, do not consider the complexity that water quality brings into management, design and governance of WUSs in an uncertain but real world. So, the author strongly suggests the use of the Full Sefficiency model, i.e., with both attributes.

3. An Example

Table 3 gives the basic inputs to Sefficiency for this particular example.

Table 3: Water quantities, qualities and benefits for the example.

Water quantities		**Comments**
Evapotranspiration, ET	0.037	
Non-reusable, NR	0	
Other Sources, OS	0	
Total Precipitation, PP	0.02	
Return Flow to source, RF	0.084	
Other Return, RP	0.02	
Abstracted water, VA	0.121	
Downstream, VD	0.963	
Upstream, VU	1	

Water Balance, MesoE	0.000	The law of water balance should be obeyed
Water Balance, MacroE	0.000	
Quality Weights - Wq		
ET	1.000	
NR	1.000	
OS	1.000	
PP	1.000	
RF	0.720	
RP	0.700	
VA	0.850	minus pollution leaching requirement
VD	0.850	
VU	0.900	
Beneficial Weights - Wb		
ET	0.920	minus non-beneficial ET
NR	1.000	
OS	1.000	
PP	0.500	
RF	0.900	
RP	1.000	
VA	1.000	
VD	0.900	
VU	1.000	
Energy		
ENN	0.000	No energy consideration

Using Table 3 and Eqs. (2), the results of Eqs. (1) are in Table 4.

Table 4: The values for the three Sefficiency levels for the Example.

Full i Sefficiencies	
MacroEs	86.2
MesoEs	90.8
MicroEs	30.2
Quantity i Sefficiencies	
MacroEb	91.2
MesoEb	99.0
MicroEb	26.0
Full c Sefficiencies	
MacroEs	21.4
MesoEs	76.6
MicroEs	30.2
Quantity c Sefficiencies	
MacroEb	27.6
MesoEb	96.2
MicroEb	26.0

Table 4 presents the clear influence of pollution (depicted in the full Sefficiencies) in decreasing Macro and Meso efficiencies. Micro efficiency does not include return flows, hence water quality differentials do not influence Micro level efficiencies. The IN efficiencies, i.e., 'i' Sefficiencies are higher than 'c' (OUT) efficiencies. The Macro level is much lower than Meso level (at least some five percentage-points). This is due to the influence of the environmental impacts of VD relative to return flows.

4. Conclusion

Sefficiency is an innovative framework that illustrates trade-offs and non-linearities among three pillars of water management and design, i.e., water quantity, quality and benefits. Any reallocation (or trade) that does not consider the influence of these pillars in a comprehensive and integrated system, such as, Sefficiency, is bound to be error prone.

Environmental impacts of water use systems are of great concern. They can manifest themselves through water quantity shortage and/or water quality degradation. In this context, the benefits, including heath and prosperity, received from these aspects of water may suffer, hence to clearly demonstrate the trade-offs of the three pillars are highly recommended. The trade-offs are also important in water footprints under international trade, which is one of the important research areas under way in linking virtual water trade and Sefficiency.

It has become customary for many policy makers and urban specialists to condemn agriculture for using most of the freshwater. Although this is true looking at a single farm under only one objective (i.e., food production), Sefficiency shows us that the reality could be very different. If we look at a water use system (WUS), such as, a farm, from the point of view of its return flows, as well as water supply and consumption, then a more comprehensive view of water arises. Additionally, if the policy makers use more than one objective (i.e., a more realistic approach), then a true and very different picture of the impacts of a WUS emerges.

Relative to any environmental impact Stakeholder involvement is vital. For a typical WUS, there are many types of stakeholders. For example, there are those concerned about water supply (VA and OS), groundwater (RP), effluents of a WUS, such as, urban and industrial wastewater (RF, RP) or agricultural return flows (RF, RP), etc. Sefficiency integrates all of these stakeholders transparently, and as such, it is a powerful enabler for stakeholder involvement.

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