**Stress-weighted water footprint assessment of agricultural policies in a water scarce region**

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**Abstract**

In this paper, the concept of water footprint (WF) was used as an indicator to determine the water consumption of an agricultural activity and then to estimate the environmental burden of this consumption by the stress-weighted water footprint ($WFeq_{H2O}$) approach considering the type and the origin of water used in order to assess the potential contribution to water scarcity in water scarce areas like Messara Plain in Crete, Greece. This region, where large quantities of agricultural products are produced, faces serious problem regarding irrigation needs coverage. In order to overcome this problem a restructuring of cultivated land and modernization of the existing irrigation systems are proposed. The purpose of this analysis is to gain insight into existing and proposed agricultural schemes in a highly importance cultivated region in Crete, Greece. In addition, another goal of the analysis is to explore and assess the potential of the water footprint concept to be used as a reliable and convenient indicator for the development of an optimal agricultural and rural policy focusing on optimal water resources management. Based on this concept, restructuring of agricultural crops in Messara Plain from 13 to, 5 besides the construction and operation of new irrigation infrastructure works, are also proposed to obtain a better water resources management. As it is shown so far in order to propose a new agricultural scheme that will involve mainly crop restructuring, a critical design parameter is the crop yield that is directly correlated to agricultural water footprint.

**Keywords:** Water scarcity, water stress index,  crop restructuring, agricultural policies, Messara plain

## 1. Background

Nowadays, the pressure on freshwater resources is rapidly intensifying with population growth, climate change and continuing economic development, causing freshwater to become a scarce natural resource in many regions on Earth. Agriculture has a significant contribution to sustainable economic development of European Union (EU) as it is the largest importer and the second largest exporter of food products. Freshwater availability is an important issue that should be considered to achieve future environmental sustainability and food security [1]. As far freshwater availability additional pressure is also paid to the authorities based on scenario analysis for 2050 that indicates blue water shortage for more than 59% of the world population [2]. In order to deal with the growing concern of water scarcity, researchers such as [3] Hoekstra (2003) and [4] Ridoutt and Pfister (2010a) have proposed water footprint (WF) as an indicator to assess the consumptive water use. Special concern was paid to estimate the fresh water consumption in agricultural sector as it is responsible for approximately 70% of total withdrawals for irrigation purposes [5]. Some attempts to estimate WF in a national or household level ([6-8]), a product ([9-12]), an activity ([13-15]) and a sector [16] have been lately performed by researchers In this paper, the WF indicator including fresh water volumes consumption and polluted water volumes was estimated for a large cultivated region in Messara Plain in Crete, Greece by the stress-weighted water footprint ($WF_{eqH2O}$) approach [4]. The purpose of this analysis is to gain insight into existing and proposed agricultural schemes in a highly importance cultivated region in Crete, Greece. In addition, another goal of this analysis is to explore and assess the potential of water footprint concept to be used as a reliable and convenient indicator for the development of an optimal agricultural and rural policy focusing on optimal water resources management. Based on this concept, restructuring of cropland and new rural infrastructure works may be considered as potential alternatives to new agricultural schemes.

**2. Messara Plain: Current State - Deficiencies – Suggested Solutions**

Messara Plain is located in the South-Western part of Heraklion Prefecture. It is the most important agricultural region in Crete and it is also among the top three highly cultivated regions in Greece after Thessalian and Agrolic plains. The area of interest (106,800ha) is part of Messara Plain (Municipalities of Tympaki and Mires) falling in the water district GR 13 whereas Geropotamos and Koutsoulidis rivers are at risk according to 2000/60 Water Frame Directive categorization. Due to the intense land cultivation and groundwater overexploitation, the area faces serious challenges in order to meet its irrigation needs. As a result, the groundwater level has considerably declined causing serious water quantity and quality issues that are more severe towards the end of the irrigation season. Geomorphologically it is characterized as hilly consisting of mainly alluvial deposits and progressively decreasing terrain until the coast, including farmland whose 92% (94,100ha) is occupied by crops and pastures. The soil infiltration is estimated to be moderate to moderately slow and the available humidity high to moderate [17]. In the very mild Mediterranean climate of the region, 13 different crops are cultivated such as olive groves, vegetables (e.g. tomatoes, potatoes), citrus fruits and grapes in open (87.6%) and covered (12.4%) cultivation systems. In the current crop scheme, the cultivation of several species (e.g. tomatoes) takes place under irrigation conditions in open and covered systems (81.5%) while 18.5% of the total area covering olive groves, grapes, wheat, barley and hay meadow crops are rainfed crops. As it is shown in Table 1, the main crop in the region is olive groves (~48%).Table 1. Types of crops grown in open and covered systems for the current and for the proposed scheme

| Crop type | **Current Scheme** | | | | **Proposed Scheme** | | | |
|---|---|---|---|---|---|---|---|---|
| | Open Systems | | Covered Systems | | Open Systems | | Covered Systems | |
| | Area (acres) | % Total Area | Area (acres) | %Total Area | Area (acres) | %Total Area | Area (acres) | % Total Area |
| Wheat (rain.) | | 3.76 | | | | | | |
| Barley (rain.) | 1000 | 3.76 | | | | | | |
| Hay meadow (rain.) | 1500 | 5.64 | | | | | | |
| Olives (rain.) | 500 | 1.88 | | | | | | |
| Olives (irrig.) | 12000 | 45.15 | | | 15000 | 56.43 | | |
| Grapes (rain.) | 300 | 1.13 | | | | | | |
| Grapes (irrig) | 800 | 3.01 | | | | | | |
| Legumes (irrig.) | 120 | 0.45 | | | | | | |
| Medic (irrig.) | 130 | 0.49 | | | | | | |
| Melons (irrig.) | 750 | 2.82 | 750 | 2.82 | 1330 | 4.98 | 1320.5 | 4.98 |
| Potatoes (irrig.) | 1400 | 5.27 | | | | | | |
| Vegetables (irrig.) | 750 | 2.82 | 750 | 2.82 | 1560 | 5.85 | 1550.5 | 5.85 |
| Tomatoes (irrig.) | 1800 | 6.77 | 1800 | 6.77 | 2060 | 7.73 | 2050.5 | 7.73 |
| Citrus (irrig.) | 950 | 3.57 | | | | | | |
| Fruits (irrig.) | 280 | 1.05 | | | 171 | 6.43 | | |

The irrigation system in the area of interest is mainly supplied by pumping wells from a degraded aquifer, so actions related to upgrade the existing irrigation systems that will significantly reduce water losses are seriously discussed at the authority level. According to the finally adopted regional plan for agriculture, irrigation water demand is planned to be covered in three phases including a) construction of a water dam, b) improvement of the existing irrigation system and c) reduction of cultivated crops from 13 crops to 5 [18]. The five (5) types of crops, in the proposed agricultural scheme, were selected based on various parameters, such as the current state of existing crops, soil and climate conditions, trends among farmers, possible outlets for the various products and the intention for quality improvement. The main goal of the crop restructuring was to achieve: a) an increase of farmers' agricultural income by producing an appropriate quantity and quality products which will become available in the Greek and international markets and b) a better management of the area's available freshwater resources.

Our analysis will primarily focus on the assessment of potential benefits from crop restructuring using the water footprint indicator with respect to available freshwater resources in Messara Plain. An estimation of WF for the current and the proposed agricultural schemes is obtained based on the stress-weighted WF approach. The WF calculations are based as far climatic parameters on mean values of the last 30 years from 4 meteorological stations in the region [18]. Also information related to area and type of crops that are cultivated in the region are obtained from the Hellenic Statistic Authority (2006) [19]. The estimated WF volumes are referred to a yearly agricultural production.

## 3. Water Footprint Concept

The Water Footprint (WF) concept was introduced in 2002 by A.Y. Hoekstra during the International Expert Meeting on Virtual Water Trade in Delft. The concept was developed in an attempt to achieve a better management of the planet's water resources [3]. The WF of a product/service is defined as the total volume of consumed and polluted water that is used to produce it [20]. WF could be expressed in terms of water volume per unit of product ($m^3$/tn) or water volume per unit of time ($m^3$/yr). According to Hoekstra (2003) [3], the WF consists of three components:

- The blue WF ($WF_{bleu}$) refers to the consumptive use of surface and subsurface fresh water resources.
- The green WF ($WF_{green}$) is the volume of rainwater consumed during the production process and it refers to the total rainwater evapotranspirated plus the water incorporated into the harvested crop.
- The grey WF ($WF_{grey}$) refers to the volume of polluted water that is associated with the production of goods and services. It is defined as the necessary water volume that is required to dilute wastewater flows to such an extent that after the disposal, water quality standards will be met in surface and subsurface water receptors [20].

For the estimation of WF, bottom-up and top-down approaches have been reported in the literature [21]. The bottom up approach refers to a process analysis that uses a detailed description of individual production processes whereas a top-down approach refers to input/output (I/O) analysis, an economic approach frequently used in environmental and life cycle analysis [21].

### *3.1 Stress-weighted water footprint ($WF_{eqH2O}$) approach*

In this analysis, the stress-weighted WF method ($WF_{eqH2O}$), a top-down approach is adopted to estimate the WF of a crop by considering three components: a) the blue water consumption, b) the grey water requirements and c) the impact of land use on blue water resources. The blue water consumption includes the direct use of blue water associated to irrigation and the indirect use associated to farm inputs (seeds, livestock feed e.t.c.) and also to supply farm services. The grey WF is similarly estimated as previously described. The land use component considers the potential of changing the availability of blue water by altering the stream flow and runoff [24].

The stress-weighted WF approach ($WF_{eqH2O}$) calculates the WF in a full product life cycle, from primary production to the consumption phase of a product, including intermediate stages like ingredient processing and product packaging for manufactured products. In $WF_{eqH2O}$ approach, the consumption of green water does not contribute to water scarcity therefore it is not included as a parameter to contribute to WF estimation. In other words, green water does not contribute to environmental flows until it reaches the ground therefore becomes blue water and it is accessible only through land occupation.

Ridoutt and Pfister (2010b) [6] argue that different forms of water consumption that come from different water scarcity locations should not be added without getting weighted. In order to account for different forms of consumption and local water scarcity, they used a water stress characterization factor, the Water Stress Index (WSI). The term WSI was initially introduced by Smakhtin et al. (2004) [25] as a river basin-specific water scarcity indicator that combines three components: a) the total available water resources, b) the total water use and c) the environmental water requirements (EWR). In their assessment of WSI, Ridoutt and Pfister (2010a) [4] considered: a) water availability, b) total water use and c) variability of precipitation in order to introduce a variation factor that will account for climate variability and non-linear stress effects.

The methodological steps taken in order to estimate WF in $WF_{eqH2O}$ approach are the following:

Step 1: The volumetric impact (V.I.) on blue water resources is calculated as the sum of blue water consumption, grey water requirement and impact of land use (L.U.) on blue water resources.

$$V.I. = WF_{blue} + WF_{grey} + L.U. \quad (4)$$

Step 2: For every river basin, V.I. is multiplied by the local water stress characterization factor (WSI) in order to calculate a stress-weighted water footprint ($WF_{s\text{-}w}$):

$$WF_{s\text{-}w} = V.I. \times WSI \quad (5)$$

Step 3: The equivalent water footprint ($WF_{eqH2O}$) is then calculated by dividing the stress-weighted $WF_{S\text{-}W}$ by the average national WSI of the country. $WF_{eqH2O}$ t is considered important because it describes the volume of direct water use which has an equivalent potential to contribute to water scarcity [24].

$$WF_{eqH2O} = \frac{WF_{s\text{-}w}}{WSI_{nat}} \quad (6)$$

The WSI calculation follows an extremely complex procedure requiring systematic data collection. For the purposes of this analysis, WSI values were obtained on watershed level based on WSI global map developed by Pfister et al. (2009) [26].

### *3.1.1 Evaluation of alternative agricultural schemes in Messara Plain based on $WF_{eqH2O}$ approach*

A prior estimation of WSI is necessary in order to obtain a WF estimation based on stress-weighted WF ($WF_{eqH2O}$) approach. According to Pfister et al. (2009) [26] classification of WSI, the Messara Plain is located at the corner of a region with a WSI value of 0.1437 which is significantly lower than the Greek national average $WSI_{nat}$ value (0.319). Also, the corresponding WSI values of the neighboring regions are extremely diverse, creating a very uncertain environment as far as the reliability and robustness of the extracted results [27]. For that reason, Kalampaliki (2012) [28] developed four scenarios considering the three diverse WSI values (0.1437, 0.9984, 0.0243) in the region and the mean WSI value of them (0.477) in order to obtain a representative estimation of the agricultural WF in Messara Plain. The aggregated WF for the current and the proposed agricultural schemes obtained by stress-weighted WF ($WF_{eqH2O}$) approach are summarized in Table 2. For covered systems, the green WF component is zero whereas the grey WF component is lower in the proposed agricultural scheme than the current one.

Table 2. WF ($m^3$) estimation for the two agricultural schemes based on stress-weighted WF ($WF_{eqH2O}$) approach

| **$WF_{eqH2O}$ ($m^3$)** | **Current Scheme (CSch)** | **Proposed Scheme (PSch)** | **Change** |
|---|---|---|---|
| Open systems | 1332085 | 1389718 | 4.3% |
| Covered systems | 236559 | 345209 | 45.9% |
| **TOTAL** | **1568644** | **1734927** | **10.6%** |

As it is concluded from the results in the proposed scheme, an increase of the total estimated WF in total water volumes ($m^3$) (~4% in open and ~45% in covered systems) is estimated (Table 2). However reliable results regarding crop restructuring in a highly cultivated region could only be drawn by examining each crop separately due to major impact of crop yield in WF ($m^3$/tn) calculations. Based on $WF_{eqH2O}$ calculation approach 9.5% more water volume is needed to meet the needs of the proposed agricultural scheme than the current one (Fig.1).

In this analysis a land use impact factor equal to zero is considered in addition to blue and grey WF components in order to estimate a total WF of a crop based on stress-weighted WF ($WF_{eqH2O}$) approach. However, the inclusion of this factor in the WF estimation is important since the effects that land uses may have in water balance of the region should be considered [29].

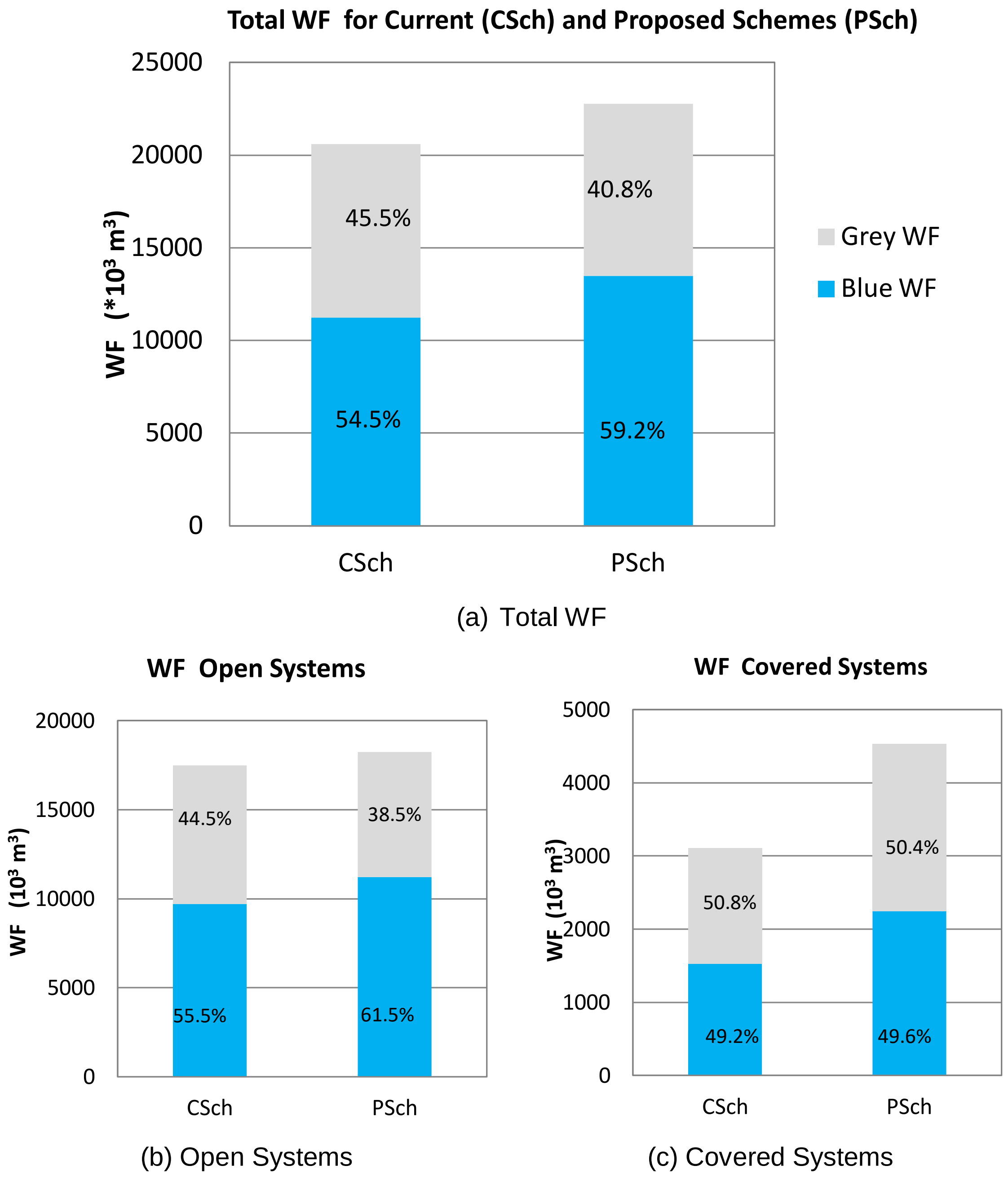


**Fig 1.** Total WF ($m^3$) for open and covered systems based on stress-weighted WF (WFeqH2O) approach

## 4. Discussion

Important decisions and actions should be taken to ensure agricultural production in Messara Plain in Crete since it remains a high priority regions for the local and national authorities. These decisions are mainly related to the implementation of modern irrigation infrastructure to ensure adequate quantity and quality of irrigation water to crops as well as on crops' restructuring and shifting agricultural production to less water-intensive crop types with significantly better agricultural yields. In this paper, the possibility of using water footprint as a reliable indicator to assess different policies related to rural development in a country is examined where agriculture is an important pillar of its economy. The main goal of this analysis was to assess the water footprint of crops in both open and covered (greenhouses) cultivation systems.

In the proposed agricultural scheme that is examined for Messara Plain besides the restructuring of agricultural crops from 13 to 5, the construction and operation of new irrigation infrastructure works is also proposed to obtain a better water resources management. As it is shown so far in order to propose a new agricultural scheme that will involve mainly crop restructuring, a critical design parameter is the crop yield that is directly correlated to agricultural water footprint. Another parameter that should be considered prior to any decision is the assessed cost and profit of the proposed new scheme. In this analysis, the assessment was based only on water requirements and effects to the agricultural production (crop yield) and not in the economical sustainability (cost and profit) of the proposed agricultural policies.

During the decision process for crop restructuring in Messara Plain, the decision makers should also consider the significant increase that is obtained in the crop yield of irrigated cropland that actually pays back the additional blue WF that is consumed. Also, decisions related to irrigation infrastructure (associated with blue WF component) and protection of the environment (associated with grey WF component) could be only obtained based on the individual values of respectively blue and grey WF components and not the total water footprint.

## 5. Conclusions

In this paper, a comprehensive evaluation of Stress-weighted WF approach, that estimate the WF of crops in a rural area is presented. The analysis has shown that in order to achieve an optimal water management in the agricultural production of a region important role, beyond its climate and soil conditions, has the type of cultivation system (open vs. covered) and the additional water demand that should be considered or not for the crops (irrigated vs. rainfed). In addition, an assessment of two agricultural schemes applied to the most highly cultivated region in Grete (Messara Plain) is performed for the first time based on WF concept. The results analysis showed that WF could be used as a reliable indicator to assess the impact of crop restructuring not only in the management of regional water resources but also in agricultural production and crop yields.

In the evaluated proposed agricultural scheme besides crop restructuring, the implementation of modern irrigation infrastructure that includes the construction of a water dam and the improvement of the existing irrigation system was also required. However, in this paper, the assessment of the proposed scheme based on WF concept was limited to crop restructuring with respect to water coverage and environmental impact to the region without considering the potential financial impacts on farmers' income due to the improvement in irrigation infrastructure.

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