Water Accounting

Subjects: Agricultural Engineering

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To improve water use efficiency and productivity, particularly in irrigated areas, reliable water accounting methodologies are essential, as they provide information on the status and trends in irrigation water availability/supply and consumption/demand. At the collective irrigation system level, irrigation water accounting (IWA) relies on the quantification of water fluxes from the diversion point to the plants, at both the conveyance and distribution network and the irrigated field level.

water demand   water availability   hydrant   distribution network

1. Definitions and Evolution

Water accounting can be defined as the systematic quantitative assessment of the status and trends in water supply, demand, distribution, accessibility, and use in specified domains, producing information for water science, management, and governance to support sustainable development outcomes for society and the environment [1][2]. The WA procedure relies upon the law of conservation of mass through water balances, which in turn identify the destination of the water used and distinguish between consumptive and nonconsumptive uses [2][3][4][5].

The WA concept has evolved over time, with different researchers and organizations contributing to its development. In the late 19th and early 20th centuries, irrigation technology advanced in Europe and North America, and new methods for measuring irrigation water supply and use were developed. For example, water meters were installed on irrigation systems to measure water applied, allocated, or delivered, and irrigation districts began charging farmers based on the volume of water used [6][7][8]. In the mid-20th century, with the increasing demand for water resources for other uses, such as industrial and urban applications, WA became more important for water resources management (WRM) among users at a larger scale [9].

The United Nations (UN) established the International Hydrological Program (IHP) in 1975 (https://www.unesco.org/en/ihp, accessed on 2 May 2023), which has evolved into a holistic program facilitating the sustainable WRM and governance, based on science, reliable data, and dissemination of knowledge. Food and Agriculture Organization of the UN (FAO) is one of the organizations that has played a major role in the development and promotion of WA in irrigated agriculture. In the 1960s and 1970s, FAO developed guidelines for WA, focused on measuring water use in agriculture for the improvement of irrigation management. In the early 2000s, FAO initiated the AQUASTAT program, Global Information System on Water and Agriculture (https://www.fao.org/aquastat/en/, accessed on 2 May 2023), which aimed to improve the global knowledge base on water resources by collecting, analyzing, and disseminating information on water resources and their use by country.

The International Water Management Institute (IWMI) developed the Water Accounting Plus (WA+) framework (https://wateraccounting.un-ihe.org/wa-framework-0, accessed on 2 May 2023) in 2013, in partnership with the IHE-Delft Water Accounting team and FAO. It applies a comprehensive approach to measuring and managing water resources in agriculture at the basin level, with a strong focus on satellite-based remote sensing (RS) data. It has been widely used in different regions and contexts [10][11][12]. The framework combines RS data with other available global datasets and ground measurements to produce WA sheets supported by graphs and tables, which provide a standardized approach to tracking water resources and their use in different sectors, including agriculture. The approach is based on the principles of Integrated Water Resources Management that emphasize the need for WRM using a holistic approach, considering social, economic, and environmental factors.

In 2018, FAO and World Water Council released a white paper on water accounting for agriculture [13], an initiative that contributed to the work plan of the Global Framework on Water Scarcity previously launched at the Marrakech Climate Conference in November 2016. The World Bank also contributed to the development of WA by developing its own framework and methodologies for tracking water resources and use [14].

Recently, FAO developed and made available the portal WaPOR (https://wapor.apps.fao.org/home/WAPOR_2/1, accessed on 2 May 2023) that monitors WP through open access of remotely sensed derived data to support water accounting at different scales. Data are available at diverse resolutions (250 m, 100 m, and 30 m) and temporal resolutions (10–day, seasonal, annual). This tool is available for monitoring and reporting on agricultural WP over the African continent and Near East.

In recent years, the concept of WA has been incorporated into the United Nations Sustainable Development Goals, which aim to ensure by 2030 universal access to clean water and sustainable water management practices (https://sdgs.un.org/goals, accessed on 2 May 2023).

To standardize the concept of water use for the different stakeholders, Molden [4] defined WA as the art of classifying the components of the water balance into water use categories, considering the consequences of human intervention in hydrological cycles and the domain of inputs and outputs according to their uses and productivity. Different definitions of WA can be found in the literature, e.g., refs. [1][2][5][15].

Agricultural WA, or more precisely and within the scope of the present review, irrigation water accounting (IWA), involves the systematic measurement, monitoring, estimation, and reporting of water resources in irrigated systems [1][2]. The methodology considers and assesses both the supply and demand aspects of irrigation supply systems [16] and integrates different uses of water into the water balance.

An initial and critical step of IWA is to define the system (3D) domain and specify spatial and temporal boundaries, which are dependent on the study objectives. It can be the root zone of an irrigated field for an irrigation event, from the water diversion to the farm gate, or an entire water basin, including surface water and groundwater, over a period of several years [17]. It also involves classifying inflows and outflows across the domain borders according to their uses. Gross inflow is the total amount of water flowing into the water balance domain from precipitation and surface and subsurface sources. Net inflow is the gross inflow plus any changes in storage. Water depletion is the use or removal of water that renders it unavailable or unsuitable for further use. It entails water that goes to the atmosphere (beneficial water consumption) or other sinks (nonbeneficial use). An example of the latter is the non-recoverable runoff and drainage because (i) it is not economically exploitable, such as saline water bodies and deep aquifers, or (ii) its quality prevents its reuse.

Outflow is the part of the diverted water that can be reused. It is divided into committed and uncommitted fractions. The first fraction encompasses the outflow that is allocated to other uses, e.g., downstream water rights, while the latter corresponds to water flowing out of the considered domain due to a lack of storage or operational measures. It is the case of water flowing to the sea, in excess of the requirements for beneficial uses [17].

2. Different Perspectives on Irrigation Water Accounting

IWA has been approached from various perspectives, each one providing different insights into the WRM and the role of irrigation in sustainable development. According to some authors, e.g., refs. [3][9], water accounting has developed from three distinct perspectives.

- The hydrology perspective: This perspective focuses on understanding the natural water cycle and quantifying the role of precipitation, evaporation, and transpiration, runoff to streams and rivers, recharge to aquifers, outflows to the sea and storage, to determine water availability in a particular region [3][4], usually a basin;

- The irrigation engineering perspective: This perspective focuses on interventions designed to utilize surface water or groundwater flows to meet irrigation requirements. It also focuses on the design, construction, and operation of storage structures, conveyance and transport of irrigation water, control structures, and on-farm irrigation systems [2][18][19][20]. From this perspective, IWA can help identify the water requirements of different crops and quantify nonbeneficial uses, such as evaporation and leakage, at both the field and the conveyance and distribution network levels. In this case, the impact of different management practices on water use efficiency and WP can be assessed. Ultimately, it can identify opportunities to modernize the CDN [19][21];

- The monitoring and evaluation perspective: This perspective focuses on the use of water accounting to support management decisions. Examples are the optimization of water distribution to farmers, optimization of irrigation schedules, use of more efficient irrigation systems, adoption of drought-tolerant crops, or accessing incremental improvements in policy and practice on both the supply and demand sides of water supply and delivery services [1][2][22]. Decisions on water management are usually made at different levels, including farms, water users' associations, and regional water planning agencies.

Other authors also debated the following perspectives of IWA, which can be considered transversal to the previous ones.

- The environmental perspective: This perspective focuses on the assessment of the impact of irrigated agriculture activities on water quality and the environment. This includes monitoring the discharge of pollutants from agricultural sources, such as fertilizers and pesticides, and evaluating the impact of agriculture on water quality and aquatic ecosystems [23][24][25][26];

- The economic perspective; This perspective focuses on the value of water resources in agriculture and the costs and benefits of its use [27][28][29][30][31]. It seeks to optimize the use of water resources to maximize agricultural productivity and profitability. This involves evaluating the costs and benefits of different irrigation systems, crop varieties, and water management practices, and developing policies and programs that promote the efficient use of water resources in agriculture and effective water allocation [18], pricing, and management [21][32];

- The social perspective: This perspective is concerned with issues such as access to water for irrigation, equity, social justice, and participation in water governance [33][34]. It involves assessing the social and cultural values of water, identifying the needs and priorities of different stakeholders, and developing policies and programs that promote social equity and participation [35][36].

An integrated perspective on IWA considers all the above perspectives and seeks to balance economic, environmental, and social considerations [37]. It aims to promote sustainable water management in agriculture that meets the needs of all stakeholders while preserving the environment.

3. Scales and Levels for Which Agricultural Water Accounting Procedures Are Developed

Agricultural WA can provide information about water availability and use at different scales [17]. The scale of application depends on the purpose of water accounting and the availability of data and resources. The following scales can be considered:

- Macro scale: This scale corresponds to the basin or sub-basin level, often encompassing multiple uses and services, including agriculture, industry, landscape, and households. Furthermore, at this scale, data should be collected on water use from multiple sources. This scale of application is useful for identifying areas of conflict and cooperation among different water users, for developing integrated water resource management plans, and for understanding the spatial and temporal dynamics of water availability and use in the basin. The WRM at the basin level sets limits to water allocations to reduce consumption to sustainable levels and encourages and supports all users to maximize the net benefit of allocated water [18]. So far, different frameworks have been introduced in this regard, e.g., IWMI-WA [4], SEEAW [38], GPWA [5], and Water Accounting Plus" (WA+) [10]. Delavar et al. [32] present a water accounting framework based on a modified SWAT model for better policymaking at the basin level. Perez-Blanco et al. [39] discuss water basin accounting definitions and concepts. Wheeler et al. [40] use water accounting at the basin level to investigate the rebound effect of groundwater extraction from subsidizing irrigation infrastructure in Australia, while the authors of [24] propose WA to study climate change effects on water resources in different river basins.

- Mezzo scale: This scale corresponds to the service level of analysis within a basin area, typically involving multiple users who share common water supply, conveyance, and distribution [19][41]. At this scale, WA is used to quantify and balance the supply and demand at the collective irrigation system [19][42][43][44], to determine WP and IF from water diversion to the root zone, and to promote effective water allocation, pricing, and management. It is the scale for which fewer scientific studies are found in the literature, and thus, further research is required.

- Local scale: This is where water availability and use are assessed for a specific area, such as a field or a farm [45][46]. WA involves measuring and monitoring water inputs and outputs, such as rainfall, irrigation water delivered at the hydrant/turnout, water use by crops, and nonbeneficial uses, such as drainage, runoff, and wind drift. Local water accounting can be used to calculate on-farm WP and IF, helping farmers to better manage their water resources, to identify opportunities for water conservation, and to reduce water waste [47].

Agricultural WA can also be applied at different levels, depending on the complexity of the system being analyzed and the level of detail required for decision-making. The following are the common levels of application.

- Sector level: This level involves analyzing the water balance and water use within the agricultural sector, including the water supply and uses for crops [45][46] and livestock [48][49]. This level of application is useful for understanding the water requirements and water use patterns of the sector and for developing strategies to sustainably manage water within the sector.

- System level: This level involves analyzing the water balance and water use for a specific system within a sector. This level of application is useful for optimizing water use efficiency within the system, identifying areas of water loss or waste, and improving the performance of the system. Examples of systems are the irrigated field and the collective irrigation service [19][47], and the specific term irrigation water accounting (IWA) can be used to characterize the system [21][50].

By applying WA at different scales and levels of detail, decision-makers can gain insights into the water requirements and water use patterns of different systems, sectors, and regions, and develop targeted strategies to manage water sustainably for the benefit of people and the environment according to the water availability. A key output of water accounting should be a common information base available and acceptable to all the key stakeholders involved in using, planning, or other decision-making processes [1][2].

4. Different Terminology with Similar Meanings: Are We Speaking the Same Language?

Several terms related to understanding and managing the use of water resources are used interchangeably with WA, despite their different meanings and implications. The vast terminology used in the literature for the different scales and levels of application constitutes a setback for a wide implementation of water accounting. The disagreement between terms and concepts often leads to poor use of the published results [27][51][52], confusion in the interpretation of data on crop water use, and comparison between different studies [38]. It is therefore important to identify and distinguish these terms and concepts, being the most common:

Water balance—refers to the calculation of the total amount of water that enters and leaves a particular system, such as a watershed or aquifer, over a specific period. It is important to adequately set the system spatial and temporal boundaries. Water balance is a key component of WA; however, it is only one part of a broader set of activities that make up water accounting [53];

Water footprint—refers to the quantification of the amount of water used throughout the entire supply chain of a product or service, from its production to its disposal. It has three components: the green component is related to the precipitation stored in the root zone, the blue one to the surface or groundwater resources, and the grey component is related to freshwater pollution [30][54][55];

Water auditing—is a process that places the findings, outputs, and recommendations of WA into a broader framework comprising governance, institutions, public and private expenditures, legislation, services delivery, and the wider political economy of specified domains [1][2][5][41];

Water allocation—is the process of assigning available water resources to various uses or users, such as agriculture, industry, and households [18][24][53][56];

Water governance—encompasses a set of political, social, economic, and administrative systems that are in place to develop the WRM and the delivery of water services at different levels of society. It comprises the rules, mechanisms, and processes through which water resources are accessed, used, controlled, transferred, and related conflicts are managed [13][57][58];

Water pricing—is the practice of setting prices for water use to reflect the true cost of water resources and encourage more efficient and sustainable use of water [31][36][59].

Furthermore, the science of hydrology and the practice of irrigation engineering have been developed at different scales [60], which contributes to a large set of different terms to conceptualize WA. A divergence of terminology can pose a challenge to understanding irrigation and other categories of water use within a broader context when irrigation becomes a significant component of basin hydrology [18]. The interpretation of the results depends on both the analyst's background and the scale of the analysis [9]. A farmer or an agronomist usually considers drainage as a loss (depleted/consumptive nonbeneficial use). However, a hydrologist working at the basin level may quantify it as a flux of water within the same system that can be allocated to other uses (nonconsumptive use), with a negligible impact on the basin water balance [38][51][61].

Understanding the interactions between the levels of analysis helps us understand the impact of management decisions and means to benefit from improvements in policy. In order to match irrigation service or basin requirements with field-level interventions, it is necessary to account for water use at the field level and then place it within the context of the irrigation service and basin levels.

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