Critical Examination of the Scope and Methodology of Water Resources Economics, Accounting and Auditing

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Abstract
The paper is central on accounting for water use and productivity water to improve water savings from accountability to sustainability. It critically examination of the scope and methodology of water resources economics, accounting and auditing. This paper presents a conceptual framework for water accounting and provides generic terminologies and procedures to describe the status of water resource use and consequences of water resources related actions. The exploratory study involves Water resources economics, water scarcity in economic theory, water accounting frameworks, water accounts, water consumption and water use, water valuation, water accounting and 'water budgets', water balance approach, water accounting plus (Wa+) and water accounting using remote sensing. Water accounting is a method of organising and presenting information relating to the physical volumes of water in the environment and economy as well as the economic aspects of water supply and use. The framework applies to water resource use at three levels of analysis: a use level such as an irrigated field or household, a service level such as an irrigation or water supply system, and a water basin level that may include several uses. An increase in water demands, exacerbated by climate change and the tightening of environmental requirements, leads to a reduction in available water resources for economic uses. This situation poses challenges for water resource planning and management. Water accounting has emerged as an appropriate tool to improve transparency and control in water management. There are multiple water accounting approaches, but they generally involve a very exhaustive list of accounted concepts.

Keywords: *Water resources economics, water scarcity in economic theory, water accounting frameworks, water accounts, water consumption and water use, water valuation, water accounting and 'water budgets', water balance approach, water accounting plus (Wa+) and water accounting using remote sensing.*

1.0 Introduction

Fresh water is vital to the functioning of all terrestrial ecosystems—the flora and the fauna that make up those ecosystems, as well as the humans. Humanity relies on water not just for drinking, but also for food production, dealing with waste, providing energy and transport, etc. To meet their needs, people harness water through dams, irrigation networks, pumps, and pipes that supply drinking water and remove waste. Through the global hydrological cycle, renewable water resources amount to 42,000 km3/year. Total water withdrawals still represent only a small share—about 9 percent of internal renewable water resources—but this average masks large geographical discrepancies (FAO, 2011). This proportion is likely to increase as the global human population increases in the next thirty years and the demand for water in developing countries catches up with that of developed countries.

Water accounting is a procedure for analyzing the uses, depletion, and productivity of water in a water basin context. It is a supporting methodology useful in assessing impacts of field level agricultural interventions in the context of water basins, the performance of irrigated agriculture, and allocation of water among users in a water basin.

As economies and populations grow, global water scarcity is increasing, and tough decisions about water allocation will have to be made. But most countries are poorly equipped to anticipate and adapt to the socio-economic consequence of increasing water scarcity because they lack sufficient information about water use and resources. Many countries compile some kind of database for water resources and water use; however, these databases are independently collected and used by different agencies and rarely integrated with economic accounts. We believe that water accounting, an approach that integrates water accounts and economic accounts, provides that missing information and has a unique contribution to make to water management.

1.1 Statement of the Problem

Water scarcity is an emerging global crisis; however, information useful for decision making related to water management seems to be lacking. Most importantly, little is known about information development over time. To sustain food and water security today and in the future, water resources conservation faces critical challenges including scarcity, waterlogging, depletion, increasing salinity, and coordination issues.

Present concerns of water use in different areas of water resources economic and accounting were raised by several researchers (Day, 1996). The attention of past studies was to enhance the water resources management by conserving the existing water sources, taming surface water use (i.e., irrigation), and improving agro ecosystems water use efficiency. Currently, there have been few prior attempts to investigate performance indicators on water resources accounting and economics in order to quantify how much water is used and saved for and from agricultural systems at different scales; consequently, further studies are suggested on the basin.

The first handbook for environmental accounting, known as the System of Environmental and Economic Accounts or SEEA (UN et al., 2003), has now been supplemented by several specialized manuals for individual resources, including one for water, known as the System of Environmental and Economic Accounting for Water or SEEAW (UN, 2005).

The System of Environmental- Economic Accounting for Water (SEEAW: United Nations Statistics Division 2007) is a conceptual framework for organizing economic and environmental data related to water. It describes key hydrological and economic concepts and define a set of standard tables for presenting hydrological and economic information, which show the interaction between water and the economy as well as water resources in the environment. The SEEAW provides a direct link from hydrological data to the System of National Accounts (SNA), the framework used in macroeconomic statistics throughout the world for more than 50 years and from which the accounting identity gross domestic product (GDP) is derived. However, there is still a considerable gap between the guidelines found in the official manuals and the practical application of those guidelines.

2.0 Water Resources Economics

It should be pointed out that water manifestly satisfies the Robbins definition of an economic go od, within "the science which studies human behavior as a relationship between ends and scarc e means which have alternative uses" by itself, and nominally there was no need of its declarat ion by fiat as above. "Water is a finite, vulnerable and essential resource which should be manag ed in an integrated manner." "Water has an economic value and should be recognized as an econ omic good, taking into account affordability and equity criteria." (Day, 1996). Water is a necessity, an impure public good and a social good (McNeill, 1998). Water is an economic good at country level (Zaag, 2002).

2.1 Water Scarcity in Economic Theory

In fact, scarcity in general was first mentioned by Malthus. Scarcity "implies a strong and consta ntly operating check on population from the difficulty of subsistence" (Malthus, 1803), the check control being imposed by agricultural production (Grigg, 2019), and is considered to be one of the basic assumptions of economic theory.

Malthusian weak flow scarcity refers to the limit on the available resources and on the extraction rate (Malthus,1803).

Malthusian strong flow scarcity refers to the weak one plus a constraint on total resources (Malthus,1803). Ricardian flow scarcity is the case where average costs depend upon the rate of extraction and Ricardian stock scarcity is flow scarcity plus the total extracted to date (Ricardo , 2004). Under additional assumptions, the theories of Malthus and Hotelling can be reconciled by the employment of an exhaustible resources model in a dynamic input-output framework (Hotelling,1931).

However, resource scarcity theory development is based more or less on Malthus and water scarc ity at regional level is not a new phenomenon as a two millennia study shows (Malthus,1803). It should be pointed out that technology is not an instrumental economic variable in the Malthusian theory,there are two types of scarcity, general and relative (Malthus,1803). The first type is Malt husian and refers to actual use of a resource in relation to a want, a need, or a requirement and th e second type, due to Robbins, refers to the alternative use of a resource in relation to competing wants (Robbins,1932). Moreover, according to Ohlsson and Turton, there are two orders of water scarcity, physical scarcity being the first order, and society's inability to manage this scarcity bei ng the second one (Malthus,1803).

It is obvious that when we refer to water economics the three main variables that exert influence on water economic behavior are existing water supply (ground and hydrological cycle), climat e and consumption/population in the regime of physical distributions, interconnections and con straints as seen in (Zisopoulou et al. (2022). Their relationship is not clear-cut as they exhibit two interesting characteristics: there are multiple interactions between many d ifferent components and multiple elements adapt or react to the pattern these elements create. Th ese characteristics correspond to definitions of a complex system, to Rind's definition in analyzin g the structure of climate and Arthur's in discussing the economy itself , and water manageme nt is amenable to Forrester's System Dynamics Model (Zisopoulou et al. (2022), which is an approach designed for complex systems.

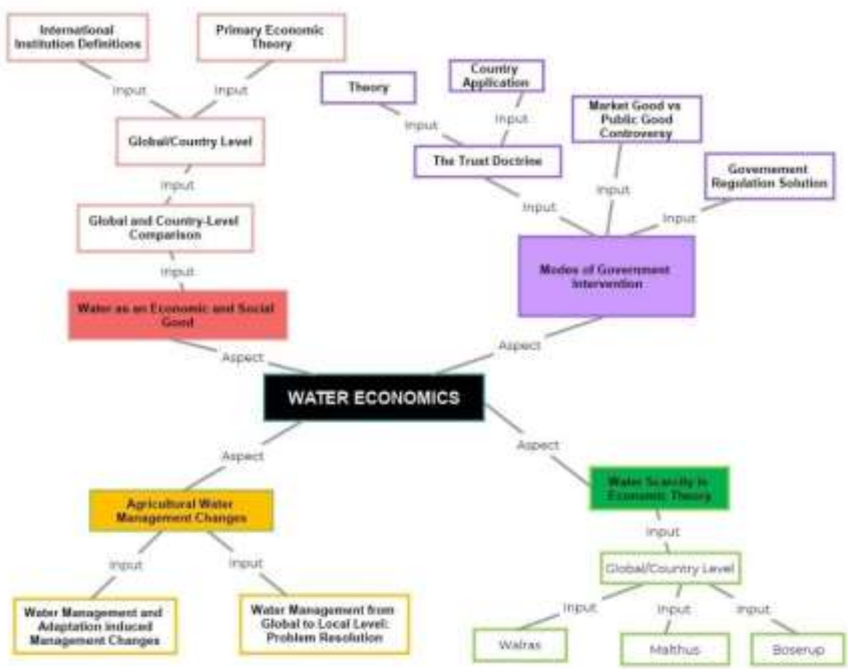

Fig. 1: Anatomy of Water Economics
Source: Zisopoulou et al. (2022)

2.2 Water Accounting Definitions

The art of water accounting is to classify water balance components into water use categories that reflect the consequences of human interventions in the hydrologic cycle. Water accounting integrates water balance information with uses of water as visualized in figure 2. Inflows into the domain are classified into various use categories as defined below. Water diverted to a use is depleted. Water is Gross inflow is the total amount of water flowing into the domain from precipitation and surface and subsurface sources. Net inflow is the gross inflow plus any changes in storage. If water is removed from storage over the time period of interest, net inflow is greater than gross inflow; if water is added to storage, net inflow is less than gross inflow.

Net inflow water is either depleted, or flows out of the domain of interest. balance approaches have been successfully used to study water use and productivity at the basin level (for example, Owen-Joyce and Raymond 1996; and Hassan and Bhutta, 1996), at the irrigation service level (for example, Perry, 1996b; Kijne, 1996; and Helal et al., 1984), and at the field level (for example, Mishra et al., 1995; Rathore et al., 1996; Bhuyian et al., 1995;Tuong et al., 1996).

Binder et al. (1997) use a regional balance technique quantifying municipal, industrial, and irrigation process uses to provide an early recognition of changes in quantity and quality of water. Often, first order estimates provide the basis for a more in-depth analysis that provides important clues on increasing water productivity.

2.3 Water Accounting Frameworks

Water accounting is an information framework that systematically integrates hydrological information from a range of data sources with other information on the economy and environment. Water accounting is part of a broader accounting view that encompasses the relationship between people, the economy and the environment. Such accounting is known by several names, including natural capital accounting, ecosystem accounting, environmental-economic accounting and, in the corporate sphere, sustainability or environment and social governance (ESG) reporting.

There are several water accounting frameworks. The focus on the SEEA is because it has been adopted over time via United Nations (UN) processes as an international statistical standard. The SEEA has several components, including the: SEEA Central Framework (UN et al., 2014); SEEA Ecosystem Accounting (UN et al., 2021); SEEA Water (UN, 2012a); The SEEA is an extension of the System of National Accounts (SNA) (EC et al., 2009). The SNA is used by virtually every country in the world for economic management and policy, and its best-known indicator is Gross Domestic Product (GDP).

Other water accounting frameworks are in use (Godfrey and Chalmers, 2012), for example Water Accounting Plus (WA+) and are referenced within the document. In general, these frameworks are aligned to different parts of the SEEA Water and use similar data sources and methods (Vardon et al., 2012). Corporate water accounting is also used by businesses outside of the water supply industry to inform organisational decisions, identifying, for example, their dependence on water (Christ & Burritt, 2018).

The distinguishing features of SEEA Water are that: it sets water within a broader set of environmental and ecosystem accounts which integrates with the SNA; water valuation is in accordance with agreed concepts and methods that are coherent with the SNA; it has been internationally agreed and standardised via UN processes; and it is the most used water accounting framework in the world.

There are also other water information systems that have much in common with the SEEA, or other water accounting systems with some of these features, but none have all of these features. Whichever water accounting or water information framework is used, the compilation of data relies on the expertise, data sources and methods from a range of professions and agencies. This includes hydrologists, economists, statisticians and accountants, and institutions of government for water management, hydrology, economics, statistics, central planning, agriculture and energy (especially where hydroelectricity is imported). Non-government research institutions, like universities, also have a role to play (Bagstad et al., 2021).

Water accounting, through the consistent application of concepts and the related definitions and classifications, provides a fully integrated information resource. This supports transparency about the connections between water, the broader environment and the economy. This, in turn, allows for comparisons between different industries and natural resources, over time and between places. Accounts reveal how changes in, for example, water availability in one part of the economy or environment, may affect other parts of the economy or environment. Such information is needed for effective water governance and management. SEEA also enables comparisons between countries to be made.

The scope of water accounting is a simplified presentation of the physical stocks and flows of water within the hydrological system, which is a part of the environment, and the economy, and the interactions between the two. Many of the flows, and in particular those within the economy and between the economy and the inland water resource system, have matching monetary flows.

The inland water resource system of a territory (e.g. a nation or river basin) is composed of all water resources in the territory (surface water, groundwater and soil water) and the natural flows between them. The economy of a territory is defined by the SNA and consists of resident water users who: extract water for production and consumption purposes; put in place the infrastructure to store, treat, distribute and discharge water; and discharge water back to the environment.

Within the scope of water accounting, are the discharge of pollutants, water quality, spending on resource management and environmental protection and water-related ecosystem services (e.g. water supply, water purification and water flow regulation services). Again, some of the physical aspects of water accounting have associated monetary values. Conversely, the monetary accounts for resource management and environmental protection have associated physical actions (e.g. installation of water treatment plants, water quality monitoring systems and catchment management).

The SEEA Water provides information on the: Stocks and flows of water resources within the environment; Pressures on the environment from the economy, including the volume of water extraction and wastewater returned to the environment; The supply and use of water and in production process and by households; The reuse of water within the economy; The costs of collection, purification, distribution and treatment of water and financing of these costs (e.g. charges to the users of water supply and sanitation services); Payment of permits for access to extract water from the environment or for the discharge of wastewater to the environment; The hydraulic stock in place, as well as investments in hydraulic infrastructure; Water quality and water pollution; The economic valuation of water resources and The inland water resource assets classes are surface water, groundwater and soil water.

Surface water is further disaggregated and includes artificial reservoirs, lakes, rivers, snow, ice and glaciers. Changes in water stocks are due to flows of water within the environment (for example between surface water and groundwater) or flows between the economy and the environment (for example river water used for irrigation). Changes in stocks can also result from increased knowledge regarding stocks (for example the discovery of new aquifers or the reassessment of the volume of already identified groundwater resources).

Beyond the scope of water accounting are the damages caused by water (e.g. by foods). Some of these damages would be recorded in the balance sheet of the national accounts as a reduction in the value of produced capital (e.g. houses, bridges and roads) and the damage to the environment would be recorded as a decline in ecosystem condition accounts. The ecosystem services of water flow regulation and river food mitigation services are also included in ecosystem accounting, but these services are provided by upstream and riparian vegetation which can moderate run-of, slow water flows, and contribute to maintenance of riverbanks (e.g. by preventing their erosion) that provide a physical barrier to high water levels.

2.4 Types of Water Accounts

The SEEA describes three general types of accounts: Supply and use tables in physical and monetary terms, showing flows of natural inputs, ecosystem services products and residuals; Asset accounts for individual environmental (including ecosystems) assets in physical and monetary terms, showing the stock of environmental assets at the beginning and the end of each accounting period and the changes in the stock and Accounts recording transactions about economic activities undertaken for environmental purposes.

The SEEA Water identifies 22 different types of standard water accounting tables, 14 supplementary tables and five indicator tables. The main types of water accounts compiled are: Physical asset accounts; Physical flow accounts – supply and use tables Monetary supply and use tables; Water emissions accounts; Ecosystem accounts containing water-related ecosystem services

Physical water asset accounts show stocks of water contained in the inland water resources by class of asset and how they change from one time period to the next. The water asset account is very closely aligned with a water balance (Vardon et al., 2012). The stocks of water recorded in the accounts may be low in some classes of water assets. For example, the stock level of a river is measured as the volume of the active riverbed determined based on the geographical profile of the riverbed and the water level, which is usually very small compared with the total stock of water resources for a nation or the annual flow of water in rivers. It is also the case that not all water resources are relevant in accounts, for example, in areas without snow, ice or glaciers, or groundwater. It is also the case that not all water resources within a particular class will be reported. For example, soil water may only be reported for the areas used for agriculture or forestry, and in such instances the scope of the reported estimate must be clear.

2.5 Stocks (Assets)

Stocks are the quantity of a particular product or natural resource at a point in time. Stocks are identified in both economic and environment statistics, although the terminology varies depending on the context, and they can be measured in physical and monetary terms. Physical stocks of water

may also have different levels of water quality. Assets are usually associated with stocks that have economic values and in the SNA stocks are recorded in balance sheets in monetary terms for non- financial assets (produced and non- produced), financial assets and liabilities. In the SEEAW stocks are recorded in the asset accounts in physical terms (the volume of water).

2.6 Flows

Flows are the quantity that is added or subtracted from a stock during a specific period of time. Flows are identified in both economic and environment statistics. Economic f lows reflect the creation, transformation, exchange, transfer or extinction of economic value; they involve changes in the volume, composition, or value of an economic unit's assets and liabilities.

In water statistics, f lows are measured as a quantity (volume, mass, or value) per unit of time: for example, m3 per year, tonnes per year or dollars per year. The f lows are usually related to particular stocks of water and f lows result in a change in quantity of the stocks. The f lows described in water statistics are (1) f lows within the environment (between inland water resources and the atmosphere, between the sea and inland water resources as well as the f lows between the different inland water resources such as surface water, groundwater and soil water); (2) f lows from the environment to the economy (abstraction); (3) f lows within the economy (exchanges of water between economic units); (4) f lows from the economy to the environment (returns and waterborne emissions); and (5) f lows with other territories (inflows and outflows with neighbouring territories). It is not always possible to establish a simple physical boundary between the economy and the environment.

3.0 Water Consumption and Water Use

The definition of water use and water consumption varies between information systems. In the SEEAW the definition of water use includes the use of water for hydroelectric power generation and the use of water for cooling in industrial processes. These types of water use are separately identified in the SEEAW tables as, while the use may be large, the water is not consumed and is usually available to other users. That is, the water may be supplied to other users in the economy or returned to the environment, with little if any change to the physical characteristics of the water

(apart from being displaced in time and space and with the addition of heat in the case of cooling water).

SEEAW definies consumption as being total use minus total supply (supply to both other economic units and to the environment, also known as return f lows). This provides an indication of the amount of water that is lost by the economy during use in the sense that it has entered the economy but has not returned either to water resources or to the sea. This happens because during use part of the water is incorporated into products, evaporated and transpired by plants. Water consumption can be computed for each economic unit, for industries and for the whole economy. The concept of water consumption used in the SEEAW is consistent with that used in water management. However, it differs from the concept of consumption used in the SNA, which instead is more akin with the SEEAW definition of water use.

Statement of Water Assets and Water Liabilities

	(Mm3)
WATER ASSETS	
Surface water assets	x
Surface water storage – unregulated	x
Unregulated major storages (>1Mm3)	x
Surface water storage – regulated	x
Regulated major storages (>1Mm3)	x
TOTAL SURFACE WATER ASSETS	x
Groundwater assets	x
Groundwater storages	x
Unconfined aquifer	x

TOTAL GROUNDWATER ASSETS	x
TOTAL WATER STORAGE (1)	x
Other water assets	x
Water rights	x
TOTAL OTHER WATER ASSETS	x
TOTAL WATER ASSETS (2)	x
LIABILITIES	
Allocation remaining	x
Other water liabilities	x
TOTAL LIABILITIES (3)	x
Net water assets	x
Opening net water assets (5)	
Changes in net water resources (6) = (4) - (5)	x
Closing net water assets (4) = (2) - (3)	x
Net water storage	x
Opening water storage (7)	x
Changes in net water storage (8) = (1) - (7)	x
Closing water storage = (1)	x

Fig. 2. New proposed statement of water assets and water liabilities

Unaccounted-for difference term in the Statement of Physical Flows, for the surface water resources.

Initial surface water resources	x
Surface water resources increase	x
Surface water resources decrease	x
Theoretical final surface water resources	x
Final surface water resources	xx
Unaccounted-for difference for surface water resources (Mm3)	x
Unaccounted-for difference for surface water resources (% with respect to the surface water supply)	xx

Unaccounted-for difference term in the Statement of Physical Flows, for the groundwater resources.

Initial groundwater resources	x
Groundwater resources increase	x

Groundwater resources decrease	x
Theoretical final groundwater resources	x
Final groundwater resources	xx
Unaccounted-for difference for groundwater resources (Mm3)	
Unaccounted-for difference for groundwater resources (% with respect to the surface water supply)	xx

3.1 Water Valuation

Values can be determined for water flows or stocks (assets). The asset value of water is often calculated via the net present value approach, which is based on the depreciated values of future flows. Water assets may also be valued via the licencing and trade of water rights. Within the SNA and SEEA, the valuation of water flows included in the water accounting is usually related to: Water as an intermediate input to production (e.g. to agriculture); Water as a final consumer good (e.g. use by households); Water that underpins financial assets (e.g. tradable water rights); Water-related ecosystem services (e.g. water purification and water regulation) and the 'sink' function of the environment (e.g. for wastewater).

These flows of water can be related to economic production and consumption within the economy as defend by the SNA, or those flows of benefits to people but outside the SNA definition of the economy.10 Ecosystem services may be used within and outside of the economy as defined by the SNA. The SEEA notes that there is no consensus on water valuation methods and does not make recommendations about methods suitable for valuation in water accounts beyond those used for the SNA (UN et al., 2021). While there is no consensus, there are more than two decades of attempts to value water in accordance with the concept of exchange value. For example, Lange (1997) made comparison of user fees, costs of delivery and the economic contribution of water to different sectors of the economy, as a first step toward estimating the opportunity cost of water. Methods specifically for monetary valuation of the water-related ecosystem services are also outlined. These include water provisioning, water filtration, water regulation and peak flow mitigation services.

For the water provisioning service, four methods are provided: Resource rent or residual method. Payments made for water supply are made for irrigation, household, and industrial uses. These payments are for the water, its transport and treatment. The transport and treatment costs (including labour and capital costs) can be deducted from the total payment with the residual value being the value of the water. It is usual for water to be provided 'at cost', that is, the payments made reflect only the capital and running costs and no payment is made for the water. In many cases, water is provided to use at less than cost. This results in zero or negative resource rents, implying no value (e.g. Obst et al., 2016). Productivity change. This is done using partial and general equilibrium models and looking at the impacts of a reduction in the supply of water to the output in different sectors of the economy (e.g. Calzadilla et al., 2013; Roson & Damania, 2016). Replacement cost methods, where a source of water is valued based on the cost of obtaining the water from the next lowest cost source (adjusted for water quality) (e.g. Edens & Graveland, 2014; Keith et al., 2017). An example would be using the cost of providing water through desalination. Value of water rights, where they are separately identified (from land values) and trading in water rights takes place such that a market is established. These rights are financial assets (Comisari & Vardon, 2013).

For the water filtration service two methods are suggested: Replacement cost method. This is the capital (i.e. infrastructure) and operational costs of purifying water to the same level of water quality (e.g. La Notte et al., 2012; Schenau et al., 2022). Avoided damage costs. This is the reduction in water purification and treatment costs that arises from having the ecosystem service. The damage to human health from water pollution is another potential approach that has been used in accounting and might also be useful and in accordance with the notion of exchange values (i.e. it is a type of avoided loss).Water regulation and peak flow (or food) mitigation services are not provided by water but by certain ecosystems. These services are, for example, provided by upland and liner vegetation, and the value of this benefit can be calculated using avoided loss.

3.2 Water Accounting and 'Water Budgets'

Water budgets are a tool for quantifying the flows of water into and out of a hydrological system. They record all water stored and exchanged on the land surface (rivers, lakes), subsurface (aquifer, groundwater) and atmosphere (precipitation, evaporation) (e.g. Healy et al., 2007). In a water budget, the rate of change of water stored is balanced by the quantity and rate at which water flows into and out of a hydrologically- defined area. A water budget closely resembles the physical water asset account.

By linking a water budget, which is largely equivalent to the physical water asset account, to the physical and monetary supply and tables, the amount of water abstracted and returned by human activity can be better understood. The SEEA Water can record in greater detail the amount of water abstracted and returned by different industries and sectors. This enables water managers to allocate the available water to different users and understand the impacts on both the hydrological and economic systems of changes in water availability, water use and expected water demand (e.g. through increased population or the growth of large water-using industries).

3.3 Water Balance Approach

The water accounting methodology is based on a water balance approach. Water balances consider inflows and outflows from basins, subbasins, and service and use levels such as irrigation systems or fields. An initial step in performing a water balance is to identify a domain of interest by specifying spatial and temporal boundaries of the domain. For example, a domain could be an irrigation system bounded by its headworks and command area, and bounded in time for a particular growing season. Conservation of mass requires that for the domain over the time period of interest, inflows are equal to outflows plus any change of storage within the domain. In a purely physical sense, flows of water are depicted by a water balance. To develop and use water resources for their own needs, humans change the water balance. Water accounting considers components of the water balance and classifies them according to uses and productivity of these uses.

How to achieve savings or increase water different levels of water use are defined for which water accounting procedures are developed: Macro level: basin or subbasin level covering all or part of a water basin, including several uses of water Mezzo level: water services level, such as irrigation or municipal water services. Micro level: use level, such as an agricultural field, a household, or an environmental use. The water accounting methodology is developed in a manner such that it can be generically used for irrigation, municipal, industrial, environmental, or other uses of water. But the focus of this paper will be on irrigation services and use of water, and emphasis will be on quantities of water at the field and irrigation service levels. In the future phases, concepts and examples will be presented from multiple uses of water and water quality.

3.4 Water Accounting (WA) Approach: The WA is the systematic acquisition, analysis, and dissemination of data on stocks and fluxes of water (from source to sinks) in natural, disturbed, or extensively managed settings. Through WA, changes in water use (WU) patterns are analyzed. The WA framework differentiates the various flows that are associated with WU and can be applied to any sector at any scale without modification. The WU is the application of water to a selected purpose (i.e., irrigation, industrial processes and among others). Typical recoverable flow fractions are between 20% and 90%. Two main factors affecting the WA are the hydrologic conditions that determine water table depths and current soil and water management practices.

The water accounting approaches involves the following parameters: Available water: the amount of water available to a service or use, which is equal to the inflow less the committed water; Basin or sub-basin accounting: the macro scale of water accounting for all or part of water basins, including several uses of water; Closed basin: a basin where utilizable outflows are fully committed; Committed water: the part of outflow that is reserved for other uses; Depleted fraction: the fraction of inflow or available water that is depleted by process and non-process uses. Depleted fraction can be related to gross inflow (Depleted Fraction of Gross Inflow), net inflow (Depleted Fraction of Net Inflow), or available water (Depleted Fraction of Available Water); Domain: the area of interest where accounting is to be done, bounded in time and space; Equivalent yield: a yield value for a base crop derived from a mixture of crops by using local prices to convert yields between crops; Fully committed basin: a water basin that has been developed to the extent that all water has been allocated or, in other words, all outflows are committed; Gross inflow: the total amount of inflow crossing the boundaries of the domain; Net inflow: the gross inflow less the change in storage over the time period of interest within the domain. Net inflow is larger than gross inflow when water is removed from storage.

Furthermore, water accounting approach entails: Non-depletive uses of water: uses where benefits are derived from an intended use of water without depleting water; Non-process depletion: depletion of water by uses other than the process that the diversion was intended for; Open basin: a basin where uncommitted utilizable out-flows exist; Process depletion: that amount of water diverted and depleted to produce an intended good; Process fraction: the ratio of process depletion total to depletion (Process Fraction of Depleted Water) or available water (Process Fraction of Available Water); Productivity of water: the physical mass of production or the economic value of production measured against gross inflow, net inflow, depleted water, process depleted water, or available water; Standardized gross value of production: a standard means of expressing productivity in monetary terms by converting equivalent yield of a base crop into monetary units using world prices; Uncommitted outflow: outflow from the domain that is in excess of requirements for downstream uses; Use level accounting: the micro scale of water accounting such as an irrigated field, a household, or a specific industrial process; Utilizable water: outflow from a domain that could be used downstream; Water depletion: a use or removal of water from a water basin that renders it unavailable for further use and Water services level accounting: the mezzo scale of water accounting for water services such as irrigation services or municipal services.

Water Accounting can be defined as the systematic acquisition, analysis and communication of data and information relating to stocks and fluxes of water in natural, disturbed or heavily engineered environments, within a geographical domain such as an irrigation system, river basin or country(FAO, 2012).

The process of water accounting consists of several steps that need to be executed in a systematic way: Data on water stocks and fluxes need to be acquired. It is important to acquire data from a wide range of sources, to be able to assess the level of uncertainty of the measurements and to identify possible errors and data gaps. This assessment of the data is also important to make sure that in the end, the different stakeholders trust the data presented in the water accounts and feel confident in using the results for monitoring and planning; The acquired data needs to be analysed and turned into information. In order to do so, data needs to be organised in a standardised manner, for example summarised at basin or sub-basin scale. Although water accounting strives to be unbiased, there are always choices to be made, however small, which influence the outcome. Documentation and transparency are thus important here.

By systematically acquiring, analysing and communicating information related to water resources, water accounting can thus: Assist in developing a common understanding of the state of water resources of a domain (such as a river basin), opposed to each stakeholder working with its own, often leading to a different understanding of a situation; Help to identify water related problems (such as water scarcity) and possible solutions; Evaluate anecdotal evidence, such as expert opinion or folklore. Water accounting can provide less biased information to check whether or not anecdotes still hold merit and thus challenge factual errors and biased views.

4.0 Water accounting Plus (Wa+): Water Accounting Using Remote Sensing

Water accounting over the years has evolved since the first introduction by Molden (1997).

It started with analysing irrigation systems using observed data. Later on remote sensing information was used to provide spatially aggregated information on the performance of the irrigation systems. In 2013, the water accounting plus (WA+) framework was developed to analyse water accounts at river basin level (Karimi et al. 2013). WA+ integrates hydrological processes, with land use, managed water flows and the services that result from water consumption in river basins. Its objective is to achieve equitable and transparent water governance for all users and a sustainable water balance. It is mainly based on open-access earth observation data which offers several benefits: All data is spatial and can thus be presented on maps or can be aggregated based on other spatial data, such as land-use classes; No-one "owns" the water accounts, meaning they can be shared by anyone to anyone, giving all stakeholders the same (amount of) information and Biases in the data are consistent among different WA+ studies, allowing for comparisons between different study areas.

4.1 WA+ Methodology

The longer term planning process of water and environmental resources in river basins requires that a measurement -reporting -monitoring system is in place. The Water Accounting Plus (WA+) framework is based on the early WA work of Molden (1997) focussing on agriculture and irrigation systems. WA+ was further developed by Karimi (2014) and Karimi and Bastiaanssen (2015) for river basin analyses to incorporate all water use sectors. Further developments include more hydrological and water management processes and focus on specific land uses. A key element of WA+ is that it separates evapotranspiration (ET) into rainfall and incremental ET, thereby clearly identifying managed water flows. WA+ includes the hydrology of natural watersheds that provide the mains generation of water in streams and aquifers, as well as quantifying water consumption. The current study utilises the WaPOR v2.0 Level 2 data (100 m resolution) for the analyses. As such, it provides a rapid WaPOR-based water accounting plus framework.

The output of WA+ is presented a number of sheets and supporting spatial maps. Remote sensing, GIS and spatial models form the core methodology, so all data has a spatial context. The accounts are reported on an annual basis, as WA+ is meant for longer term planning. Software tools have been developed that automatically collect and download data from WaPOR database as well as for the calculations.

The rapid WA+ mainly uses WaPOR data such as the level 1 monthly precipitation and level 2 annual time series of land cover classification, interception and actual evapotranspiration and interception. External data sources used include GRACE satellite data for estimating the change in storage in the basin, Global Reservoir and Dam Database to identify dam locations and extents, the World Database on Protected Areas to identify the protected land uses, and the map of top soil saturated water content (de Boer, 2016).

WA+ is an accounting framework based on the landscape, land use is therefore an important input into the analyses. Four main categories of land and water uses are distinguished in WA+ (Karimi et al., 2013): Protected Land Use; areas that have a special nature status and are protected by National Governments or Internationals NGO's; Utilized Land Use; areas that have a light utilization with a minimum anthropogenic influence. The water flow is essentially natural; Modified Land Use; areas where the land use has been modified. Water is not diverted but land use affects all unsaturated zone physical process such as infiltration, storage, percolation and water uptake by roots; this affects the vertical soil water balance; Managed Water Use; areas where water flows are regulated by humans via irrigation canals, pumps, hydraulic structures, utilities, drainage systems, ponds etc.

4.2 Water Balance

Just as a regular accountant evaluates the balance between revenues and expenses, an important part of the WA+ framework is the assessment of the water balance, which compares the change in storage ($\Delta S/\Delta t$) through the difference between incoming and outgoing water flows in a certain domain over a certain period of time: The evaluation of the water balance is important for several reasons. First of all, it helps water managers to understand whether a basin is facing a quantitative risk or not and helps identify drought and water scarcity situations, and monitor unsustainable practices. If, for a long enough period of time, the inflows into a basin are smaller than the outflows, sooner or later there will be a water deficit.

Furthermore, the water balance gives water managers an idea of the temporal variability of the availability of water resources. Depending on the temporal resolution and period of the accounts, intra- and inter-annual variability of the water resources can be established. In particular, reporting water conditions on a monthly basis allows for the identification of seasonal water shortages and excesses. It can identify periods when inflows exceed outflows, and water is stored, while during other periods, outflows can exceed the inflows and storage is depleted. Water Accounts can also identify long term trends which could indicate unsustainable utilisation of the water resources by depleting the water storage.

The water balance components are reflected in the Resource Base sheet of WA+. On the left side, the grey arrows show different water flows into the basin (adding to the Gross Inflow). These flows consist of precipitation (P, including internally recycled ET) and flows into the basin from either surface water (e.g. through inter-basin transfers) or groundwater as well as flows from desalinated water. Several remote sensing products of rainfall are available to estimate the basin precipitation, often the largest incoming flux of water in a river basin. Data on the other inflows has to be obtained from the field.

The grey box at the bottom left of the Resource Base sheet (ΔS), represents changes in storage within the basin. A depletion of the storage adds water to the water balance, while an increase in water storage indicates water is taken out of the water balance. The water storage depletion makes water available for the users, however, this is not sustainable in the long run. The change in storage is estimated using data obtained from the Gravity Recovery and Climate Experience (GRACE). The Gross Inflow plus the change in storage becomes the Net Inflow.

The other side of the sheet shows blue arrows representing flows leaving the basin through the Outflow, which consists of surface water outflow, inter basin transfers and through groundwater flows. The green arrow indicates the Depleted Water through evapotranspiration. Evapotranspiration is usually the largest of these flows, and can be estimated using remote sensing information. To estimate the other components of the outflow, information from field observations is required.

4.3 Utilizable and Non-Utilizable Flows

Besides showing the water balance and the quantities of green and blue water flows in a river basin, the Resource Base sheet also gives a breakdown of the Exploitable Water based on its current utilisation, estimated non-utilizable and reserved flow. The Available Water for further productive and economic use excludes non-utilizable flows and reserved flows.

Non-Utilizable flows are defined as the amount of water which is not available for water resources development. This results from spatial and temporal availability of the water. Part of the flow that occurs rapidly (e.g. flash floods) or precipitation that falls in the most downstream part of the basin, which often has limited options for storing water and is therefore termed non-utilizable.

Besides the non-utilizable flows, a portion of the blue water is reserved. This includes water which is part of a sharing agreement with a downstream country, or a portion of the water in a lake or river that needs to be left to ensure the health of the local ecosystem.

In most basins, part of the available water is already used (Utilised Flow), this includes the amount of managed water use and non-recoverable flow which is a function of the pollution rate in the basin, estimated using the Grey Water footprint. The remainder is called Utilizable water, which provides an estimate on the potential for water resources development.

4.4 Wa+ Sheets

The WA+ sheets provide a wealth of information related to water management in a systematic way. However, these sheets are not always easy to interpret and only provide a snapshot of the situation (either for a month or a year). For water managers, it is important to compare different years, analyse the spatial patterns of data presented in the sheets and to identify temporal trends.

The following water accounting plus sheets are involved: Evapotranspiration: Quantifies water consumption for all land use classes throughout the basin; Describes the anthropogenic impact on ET; Helps to understand impact of land use planning on consumptive use; Relates water consumption to intended processes, by estimating (non-)beneficial ET. Agricultural Services: Quantifies the agricultural production (kg/ha) in terms of food, feed, timber and fish Presents the related water productivity (kg/m³).Based on the water consumption reported in evapotranspiration. Beneficial water consumption and shifts from irrigated to rainfed crops and agroforestry systems. Utilized Flows: Provides an overview of all man-made withdrawals; Estimates natural withdrawals due to seasonal floods, shallow groundwater tables; Describes surface-water and ground-water contribution to total withdrawals; Distinguishes between consumed and non-consumed water and shows the impact and Recognizes recoverable and non-recoverable flows. Surface-Water: Quantifies the natural and actual river flows along a transect of tributaries; Determines the surface water availability and utilizable withdrawals in any location in the river basin; Describes storage in tributaries and main rivers for regulation purposes; Assist in the planning of infrastructure and water resources development and Helps preparing (surface-) water allocation plans, also for dry years. Groundwater: Helps to understand the role of groundwater in renewable water resources; Identifies aquifers which are used as a storage reservoir for droughts and their role and Helps preparing safe groundwater withdrawal plans and thus prevent declining groundwater tables.

5.0 Conclusion and Recommendations

This paper presents concepts and definitions necessary to account for water use, depletion, and productivity. The accounting procedures and standards given here are designed to be universally applicable for evaluating water management within and among all sectors. A goal of this approach is to develop a generic, common language for accounting for uses of water. This conceptual framework provides: Water accounts are a framework for assembling multiple data sources into a coherent information system. There are many types of water accounts covering the hydrological cycle, water quality, the water supply and sewerage industries, water fees and charges, defensive and restoration expenditures, and financing as well as for water-related ecosystem services, like water purification, water regulation and food control. Through the consistent application of concepts, definitions, classifications and structures, water accounts can be linked to other types of environmental information and in particular ecosystem accounts and the System of National Accounts (SNA). The SNA is used by every country in the world for economic management and policy. Water accounting can provide the integrated information that can support water governance and management, just like the national accounts support economic management and policy.

Water accounting has evolved over more than three decades, and this experience is brought together in the System of Environmental-Economic Accounting (SEEA). Nearly 100 countries use or are developing this system, and 73 countries and regions have produced water accounts, using a range of data sources and methods, and with production growing steadily over time. The production and use of water accounting is global and is undertaken in all types of countries (e.g. low- to high-income, small to large, and at various levels of water stress).

This review of water accounts provides examples of their production and actual or potential use in water governance and management. The review also assesses the strengths and weaknesses of water accounting, enabling best practices to be identified. Best practice includes: a collaborative development process recognising the diversity of stakeholders and stakeholder values to ensure the relevance of the accounts; comprehensive coverage of water resources (surface, ground and soil water), industry and sectors (e.g. agriculture, mining, energy, water supply and sewerage industries plus households); development of multiple account types (stocks and flows, physical and monetary measurement units); regular, frequent and timely production; clear statements of data quality (including limitation); and using a continuous improvement process. With water accounts, decision makers in water governance and management will have a rich information source that can be used to balance the competing demands for water and can ensure that water use is sustainable and equitable. In this, water accounts can feed into decision-making processes and be used to identify problems and to design, implement, monitor and adapt solutions.

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