Food and Agriculture Organization of the United Nations

WORLD WATER COUNCIL

WATER ACCOUNTING FOR WATER GOVERNANCE AND SUSTAINABLE DEVELOPMENT

WHITE PAPER

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[1] University of Nebraska – Daugherty Water for Food Institute (DWFI); Food and Agriculture Organization of the United Nations (FAO); International Water Management Institute (IWMI); International Commission on Irrigation and Drainage (ICID); UNESCO Institute for Water Education (UNESCO-IHE); UNESCO World Water Assessment Programme (UNESCO-WWAP)

FOREWORD

This White Paper has been prepared by the Food and Agriculture Organization of the United Nations (FAO), International Commission on Irrigation and Drainage (ICID), International Water Management Institute (IWMI), University of Nebraska Daugherty Water for Food Institute (DWFI), UNESCO Institute for Water Education (UNESCO-IHE) and UNESCO World Water Assessment Programme (UNESCO-WWAP) as a partner initiative of the World Water Council (WWC).

The White Paper is aimed principally at high level policy-makers, to promote and encourage policy support and investment for water accounting. In many river basins, lack of progress towards sustainable development can be traced to constraints imposed by limited availability and access to water. This paper follows the accepted view that barriers to economic growth, food production, poverty reduction and environmental protection can be mitigated through good water governance. But good water governance needs underpinning by a clear understanding of hydrological processes, more and better quality data, and a means of interpreting it for a wide range of professionals across the water and water-using sectors, to provide common understanding and agreement on the means of improving water management. This is the essence of water accounting.

Water accounting is not new, it has been a topic of discussion and research for over 20 years. It is still an evolving area of study but the growing concerns over the future of limited water resources means that it is timely to look at ways of putting it into practice.

We hope this paper will stimulate interest at the highest political level in the vital role water accounting can play and the benefits it can bring to managing scarce water resources and achieving sustainable development. It is an often-used phrase but a true one nonetheless for water resources – '*we cannot plan and manage what we do not measure*'.

GLOSSARY

Water accounting is the systematic quantitative assessment of the status and trends in water supply, demand, distribution, accessibility and use in specified domains, producing information that informs water science, management and governance to support sustainable development outcomes for society and the environment (FAO, 2012, 2016).

Water auditing builds on water accounting to advise water governance. It sits between water accounting and water governance. By examining trends in water supply, demand and productivity, water auditing examines features of water governance such as institutions, public and private expenditure, laws and the wider political economy of water in specified domains (FAO, 2016).

Water scarcity and water shortage. Water scarcity is excess of water demand over supply and is largely driven by human, economic, and societal factors. Water shortage is a natural phenomenon witnessed during droughts.

Water supply enhancement and water demand management. There are two recognised ways of overcoming water scarcity. Water supply enhancement aims to boost the supply of water using technologies such as increasing storage by building dams, desalination, and inter-basin water transfers. Water demand management aims to reduce the net consumption of water by a variety of means. Examples in urban water supply include introducing water meters and water pricing.

Water management concerns the active management of water on a daily, weekly, seasonal and annual basis using combined operations involving people, infrastructure, finance, and other inputs and resources.

Water governance is the range of political, social, economic, and administrative systems that are in place to develop and manage water resources and the delivery of water services, at different levels of society (Rogers and Hall, 2007). Governance comprises the rules, mechanisms and processes through which water resources are accessed, used, controlled, transferred, and related conflicts managed. Governance recognises the critical political dimensions of those resources which are increasingly contested. (GWP, 2014). Essentially, governance systems determine who gets what water, when and how, and who has the right to water and related services and their benefits (Allan, 2001)

KEY MESSAGES: EXECUTIVE SUMMARY

WHY WE NEED WATER ACCOUNTING

There is growing interest in water accounting, why it is needed, what benefits it brings, and equally important, how it can be put into practice. Water accounting is about quantifying water resources and uses of water, much like financial accounts provide information on income and expenditure. Interest in water accounting is based on the premise that '*We cannot plan and manage what we do not measure*' – a statement that few would disagree with.

However, given the current focus on water as a precious and limiting resource, the risks of extreme floods and droughts, and water's central role in the 2030 Agenda, it is difficult to understand why so little attention is given to water accounting and to making sure we have enough water.

Indeed, estimates suggest that by 2050, if we continue with our current approach to water management, global water demand will exceed supply by over 40%, which would put at risk 45% of global GDP, 52% of the world's population, and 40% of grain production (WWDR, 2016). This concern is supported by the World Economic Forum that consistently ranks water crises as a top global risk (WEF, 2015).

Reports from South Africa (January 2018) suggesting that Cape Town may be the world's first major city to face the prospect of running out of water following severe drought, is a timely 'wake-up call' for everyone to focus on accounting for water.

Water accounting…

Water accounting helps to make sense of how much water is available and how it is allocated to make sure the taps do not run dry. This, in its simplest form is what water accounting is about.

But it is much more than this. Water accounting is about understanding the hydrological cycle, assessing spatial and seasonal variations in rainfall with unpredictable extremes of floods and droughts. It must take account of medium and long-term changes in demand across all water users – communities, farming, energy, industry, and the environment – and inform water infrastructure investment such as pumping, storage, and planning for climate change.

Society needs more accurate information and answers to the key questions about water supply and demand. More data are needed but simply doing more, or more accurate, water measurements and assessments is not enough. Water accounting *per se* is of little use. But as a tool for understanding and resolving water problems and supporting water management, it is invaluable. The question then is how best to use this tool.

A foundation for good water governance

Water accounting's main role is to provide sound, reliable data as the foundation for good water governance. Water governance is widely accepted as the major weakness in water resource management in most developing countries. According to the World Bank[2], what makes water governance so particularly challenging is, the '*uncertainty about the amount and quality of water available from year to year, in terms of both stocks and flows*'. This is where water accounting fits into water governance and management.

But how does water accounting connect with water governance? The answer lies in *water auditing*. Like financial audits, this provides the qualitative judgements to the water account. It is the means of placing findings, outputs, and recommendations of water accounting into the broader societal context of water management, water supply, and water services delivery.

Together water accounting and water auditing support good water governance.

Many benefits flow from water accounting

Water accounting, together with water auditing, can improve understanding of the 'cost' in water terms of sustainable development; the level of water governance needed to deliver sustainable water services; and the water implications of delivering and achieving all 17 Sustainable Development Goals (SDGs).

Effective water accounting is inclusive and brings together different water users from different backgrounds, cultures, and levels of education. It can create a common 'water' language and understanding among water managers and stakeholders.

Water accounting can help to identify cross-sector water problems. Organisations that tend to work in 'silos' often influence and shape their problems with little regard to how it affects others. Working together enables everyone to address problems collectively, achieve consensus, and establish resource needs and data requirements.

Water accounting can improve transparency over water allocations and enable stakeholders to challenge policy-makers to adopt sustainable solutions that may be at odds with short term voter, legal, fiscal interests.

Water auditing enables water accounting to inform debates about regulatory, ownership, and management roles of public, private, charitable, and water user organizations.

The way water is governed determines the usefulness of water accounting. Water accounting can improve water governance, but the reverse is also true.

Water accounting is not a new idea, yet it is an alarmingly simple one. Water accounting alone cannot resolve the problems of water governance and managing

[2] World Bank (2006), Good Governance for Good Water Management.

water resources, but it can go a long way to improving and reforming governance by providing the information needed to support sound decision-making.

RECOMMENDATIONS AND MESSAGES

The main recommendations and messages coming from this review are about adopting water accounting and supporting its development.

Reasons for adopting water accounting

There are many good reasons why policy-makers should adopt water accounting:

Building sustainable development

Policy-makers who adopt water accounting can make a significant contribution to sustainable development. This would ensure that plans and related SDGs are monitored and 'costed' in terms of how much water they use or consume by asking the question "*How much water will this plan need, and can it be met from existing supplies?*"

Resolving conflicting water allocations and trade-offs

The role of governments is changing from providing development to providing regulatory and oversight services. This role of 'honest broker' will need evidence provided by water accounting to manage excessive and conflicting water demands and negotiate trade-offs.

Examining infrastructure and institutions

Infrastructure and legacy water laws, prices, rules, and tenure determine who gets what water in a river basin, especially when there is water shortage. Water accounting provides transparency for how water allocations are made and how trade-offs are addressed for improved water governance.

Preparing for drought and emergencies

Water accounting can support drought preparedness. River basins and their populations face increasing risks of drought which can result in starvation and death for impoverished people, and seriously harm economic output, and natural ecosystems. Water accounting underpins 'Monitoring and early warning'; one of three pillars recommended for drought policy, planning, and preparedness. It provides information to assess vulnerability to drought and its impacts. It supports decision-making for mitigating drought impacts and responding to short, medium, and long-term emergencies.

Asking questions of water professionals

Policy-makers see the world from an investment and intervention point of view. Water accounts enable them to task water professionals with questions that facilitate sustainable development and help solve water-related problems, such as how to save water in different sectors? And will a dam or groundwater development improve water supply and who benefits?

Reasons for supporting water accounting

Water accounting will need support at the highest political levels for nations to adopt and expand water accounting services and skills.

Checking water accounting capabilities

Policy-makers should recommend water accounting focal points are established in-country and related skills strengthened as a service within all water related government departments. This should go hand-in-hand with a review of existing water accounting facilities, especially those for public-good problem-solving, such as water allocation in river basins and from aquifers.

Funding hydrological data collection and analysis

Governments, as a matter of priority, must invest in more quality data collection as the basis for effective water accounting. A significant gap in many countries is the lack of hydrometric infrastructure (e.g. gauges) at field and basin levels to gather hydrological basic data, such as rainfall, evaporation, groundwater levels, and river flows. Data is also needed on water demand from agricultural, urban, industrial, and environmental sectors.

Sharing hydrological data and information

Hydrological information must be shared so that stakeholders have better oversight of water issues. Too often it is treated as a strategic asset which cannot be shared with scientific organizations, water users, and other third parties. Concealing data, or putting data behind an expensive paywall, contributes to a downward cycle of poor accounting and poor water management.

Sharing water accounting expertise and methods

Sharing water accounting expertise goes beyond sharing water data. There are many organizations working on water accounting from their own perspectives; with 'sharing' only taking place through websites and publications. More collaboration among different water accounting groups and specialists would greatly improve water accounting methods.

Commissioning research

Developments in water accounting in national and international research institutes and universities is not well funded. The need is to establish and expand research units working on different accounting methods including the use of Earth Observation, mobile and basin/field hydrometric sources, as well as from different water using disciplines. Research is needed to map alternative ways of acquiring data, establish common water metrics, and develop methods that better capture the connections among water users, support SDG monitoring, and investigate early warning systems for emerging water risks.

Championing a global centre of expertise

A global centre of excellence on water accounting or a network of centres sharing expertise and working on common projects would benefit all nations and avoid unnecessary duplication of effort and gaps in knowledge. Centres could host dif-

ferent accounting methods, disseminate information; foster debate, and provide 'one-stop-shops' for expertise on water accounting and water auditing. For everyone's benefit, future progress will require that protagonists of different water accounting methods agree on methods, measurement, metrics and terminology.

1. INTRODUCTION

Household accounting is common in everyday life. Money is a precious and limited asset and so it is vitally important to know how much is coming into the home and how much is being spent. Budgets and bank accounts all help to keep track of income and expenditure. Businesses also need accounts and accountants to budget and monitor cash flows to ensure profitability and sustainability.

It is thus paradoxical that we do not give similar detailed attention and priority to accounting for water. It is a precious and limited resource and water scarcity is increasing at a time when water resources are recognised as central to implementing the UN 2030 Agenda for Sustainable Development. Indeed, estimates suggest that by 2050, if we continue with our current approach to water management, global water demand will exceed supply by over 40% which would put at risk 45% of global GDP, 52% of the world's population, and 40% of grain production (WWDR, 2016). It is no coincidence that the World Economic Forum consistently ranks the water crises as a top global risk (WEF, 2015).

Water accounting can help us to make sense of how much is available and how it is allocated to make sure the taps do not run dry. This, in its simplest form is what water accounting is about.

But it is much more than this. Water accounting is about understanding the hydrological cycle, assessing spatial and seasonal variations in rainfall with unpredictable extremes of floods and droughts. It must take account of medium and long-term changes in demand across all water users – communities, farming, energy, industry and the environment – and inform water infrastructure investment such as pumping, storage, and planning for climate change. Water accounting is not just for hydrologists. It can help to identify problems across different water using sectors within river basins and build resilience to climate change. And equally important, it can help to create a common language to interpret and communicate water resources data to the many different people involved in manging water who come from different backgrounds, cultures, interests, and levels of education.

Water accounting is not new, it has been a topic of discussion and research for over 20 years. It is still an evolving area of study but growing concerns over future limited water resources mean that it is timely to look at ways of putting it into practice. So how does water accounting support water management?

The short answer is water accounting provides the foundation for good water governance which in turn underpins sustainable development. There is now a widely held belief that '*the world water crisis is mainly a crisis of governance*' (GWP, 2000) and that water governance and politics play a powerful role in a country's development pathway and in shaping policies. Technology is essential to harness, monitor and manage water, but it is not enough. Good water governance is central

to managing water supply and demand and this depends on how effectively people and water institutions undertake this management function. However, in most developing countries, institutions with water management responsibilities have been less effective in this new era of scarcity.

Water accounting alone cannot solve the problems of governance, but it can go a long way to underpinning and improving water governance by providing the information needed for sound decision-making. It is an often used phrase and true for water management '*We cannot plan and manage what we do not measure*'.

The mission of achieving sustainable use of water resources to support food security in 2050 and beyond is linked closely to several of the goals and preliminary objectives of the United Nations Sustainable Development Goals initiative [Box 1].

Box 1. Water accounting in California

"Understanding California's water balance sheet – how much there is, who has claims to it, and what is actually being 'spent' – is key to effectively managing the state's limited water supply in support of a healthy economy and environment. The latest drought has spotlighted serious gaps and fragmentation in California's water accounting system.

Better information alone will not solve California's water problems, but it is essential for effectively managing the state's scarce water resources. Making a commitment to comprehensive, authoritative, and user-oriented water accounting now will help California address periodic droughts and prepare for a warmer, and possibly drier, future.

Source: Escriva-Bou, *et al.*, 2016.

This White Paper explores water accounting, how it can support good water governance for sustainable development; and how it seeks to galvanise support for water accounting to offer better policy and decision-making.

Section 2 of this paper describes in more detail the growing interest in water accounting, its potential role in dealing with rising water demand, water scarcity, and asks the questions – Why water accounting? and What is it?

Section 3 examines why we need water accounting and how it will help in managing a wide range of common water management problems such as limited water availability, water variability, and improving productivity.

Section 4 describes the confusions and myths that surround water management and the need for common water language to interpret and communicate water resources data among many different stakeholders.

Section 5 introduces the concept of water auditing which places the findings, outputs, and recommendations of water accounting into the broader societal context of water management, water supply, water services delivery, and its role in the 2030 Agenda for Sustainable Development.

Section 6 draws conclusions on society's need for more accurate answers to questions such as how can sustainable development be costed hydrologically? What is the supply of water? How can it be increased? And How can it be sustainably managed? It offers policy-makers recommendations and messages for adopting and supporting water accounting.

2. THE GROWING INTEREST IN WATER ACCOUNTING

Rapidly changing conditions necessitate a new approach

Increasing pressures on water resources have major implications for water accounting.

- **Sustainable development needs and aims are accelerating.** Driven by rising populations with greater wealth aspirations, national and local governments and corporations are increasingly concerned with sustainable growth that does not erode underlying ecosystems (UN, 2017). These ambitions can be seen in the SDGs and in other strategies (e.g. private companies striving for "green growth"). This factor means that plans for economic development need to verify their demand for water and test their impact on existing patterns of water allocation.
- **Water supplies are changing**. A combination of changing climate, depletion of major aquifers, increasing pollution, and changing land use and agricultural intensification means that accessible supplies of predictable clean water are less common and less affordable. Water accounting is needed to more accurately understand how water supplies are changing.
- **Water demand and competition are rising.** A combination of population growth, urban growth, rising and changing food demands and the need to secure environmental flows in rivers is leading to higher demands for water (Haddeland *et al*., 2014). This means that water accounting is necessary to discern the genuine demands for water expressed in ways that assist water governance and mitigate water competition.
- **Water data are becoming more complex.** Alongside improving data technologies, generating water data is more prevalent, but many gaps still remain (Merrey, 2015).[3] The future will see an even greater need for accurate generation, analysis, and synthesis of water data to help deliver better water management and water governance. Water accounting will be at the centre of making water data work.

These dimensions can be evaluated at each of the relevant levels or scales by examining indicators pertaining to global, national and household food security.

Given the increasing competition for water found in many river basins (plus the emergence of technologies such as water recycling and desalinization of water for drinking supplies) the gap is narrowing between available supplies of water and rising demand for water. As a result, better water governance is needed to manage

[3] The UN Secretary-General's Independent Expert Advisory Group on a Data Revolution for Sustainable Development states; "too many countries still have poor data, data arrives too late and too many issues are still barely covered by existing data" (IEAG 2014, quoted in Merrey, 2015).

increasingly interconnected uses and users. In this more pressurized world, water accounting is the vital key to unlock water governance reform that can lead to better management and longer-term investments in water supply technologies such as desalination and storage, and water demand technologies such as metering.

But *why* water accounting?

There are four main reasons for this:

1. **The lack of water information is harming the case for water reform.** As the Science editorial introducing Vörösmarty *et al*. (2015b) observes: "*Major questions persist regarding the practice, policy and the underlying evidence and methods to inform both.*" And the World Water Assessment Programme (WWAP, 2014) goes further: "*lack of data puts water resources management at a political disadvantage in terms of priority decision making.*" In turn, this means society runs the risk of making water-related mistakes in the pursuit of sustainable development – investments that literally "run dry" or divert water from established uses.

2. **Water accounting supports all other forms of water practices**. Water accounting is a collection of methods that feeds into other sectors and practices such as river basin management, water and sanitation, irrigation management, and infrastructure design and implementation.

3. **Water accounting is a practical step that can be supported by all organizations working on water issues.** Water accounting covers methods that apply to specific problems, conducted by people working with water. The exercise of water accounting can create common perspectives among different users.

4. **Water accounting is an essential foundation for water governance.** Water auditing provides the connection between water accounting, water governance, and sustainable development.

What is water accounting?

Water accounting comprises different approaches to quantifying water resources in much the same way as finance does. It is the systematic study of the current status and trends in water supply, demand, distribution, accessibility and use in domains that have been specified (FAO 2012, 2016). Water accounting includes any scientifically accurate quantitative analysis and reporting of water resources to support scientific, management, governance and development outcomes.

Water accounting for water governance and sustainable development draws together four broad approaches, each of which has its own subset of methods:

The water accounting and water auditing framework. Developed by FAO (2012, 2013, 2016) this approach connects water accounting to water auditing with the specific aim of reforming water governance. The framework incorporates the quantitative rigour of water accounting with a wider social process and dialogue-driven analysis of water governance.

Basin water accounting (exemplified by WA+). Basin water accounting is an important method to assess how supplies of water are distributed to and consumed by different sectors or uses. Developed by the International Water Management Institute (IWMI) in partnership with UNESCO-IHE, Water Accounting Plus (WA+) uses public-domain remote sensing datasets to analyse the water flows, fluxes, stocks, consumption and services from complex river basins, countries or sectors (Karimi *et al*., 2013). Over the past few years the increasing availability of data from earth observation satellites has dramatically changed our ability to quantify water resources at different scales.

Hydrological methods. Found in the traditions and ongoing developments in the field of hydrology, these methods help to assess different water resources and observe changes to the hydrological cycle (such as changes in rainfall, groundwater levels or river discharges). Hydrological data is needed at all scales from the field to the basin..

Sector- or user-specific methods for determining operational performance and risks. Each sector, user or system develops particular methods for assessing performance and risks within its own domain. For example, irrigation systems can generate summary or time-step statistics on farm productivity, efficiency, infrastructure operation and so on (see Section 4 below).[4] In another example, a corporation, supply chain or sector (e.g. clothing or food type) can develop and benchmark its water footprint using a number of different methods (Hoekstra, 2017; Christ and Burritt, 2017).

While Section 3 further explores the applications of water accounting, a number of summary points can be made here:

- The selection of water accounting methods is rarely straightforward but must fit the problem and context.
- The risk of a 'blueprint' approach to water accounting is always present; water accounting must be tailored to the problem.
- Hybrid methods arising from two or more approaches are common.
- Quantitative water scientists, engineers and professionals must work closely with managers and policy-makers to ensure analyses focus on real-world problems rather than the protocols of the quantitative method.
- Gaps in water supply data (e.g. rainfall, river flows, groundwater) and a lack of water demand data (e.g. irrigation, factory, household and retail sectors and systems) are substantial and perennial problems.

[4] Some of these can be conducted by local users applying informal simple measures such as days taken to complete the irrigation of a farm (see also FAO, 2012, on informal monitoring of groundwater management).

3. WHY IS WATER ACCOUNTING NEEDED?

Many concerns drive the need to be smarter and more knowledgeable about sustainable development, water governance and the role of water accounting. These concerns are often expressed differently in diverse river basins, creating a variety of conditions that require adaptive and tailored responses.

Sustainable development and the SDGs

Water accounting helps to monitor and achieve all the 17 SDGs on economic growth, poverty reduction, and environmental protection. Not only is water used for all human, social, economic and natural activities, water is explicitly linked to meeting SDG 2 on food, SDG 6 on water, SDG 7 on energy, SDG 13 on climate adaptation and SDG 15 on terrestrial ecosystems (UN, 2017; Merrey, 2015). Economic planners and environmental organizations need water accounting to cross-check whether their plans make hydrological sense (i.e. is there enough for all users and uses?) and to answer the question: "Where will the water come from?"

Limited new supplies of water

Water accounting informs us that at the global scale the total amount of freshwater available for humans and the environment is more or less fixed, and many basins are unable to locate new supplies of freshwater (Mekonnen and Hoekstra, 2016). Nevertheless, society rightly asks how water supplies can be boosted, recognizing that they vary considerably over time and space. Some solutions, known as supply enhancement solutions, include inter-basin transfers between catchments, desalination of saltwater, building storage to capture floodwater, recycling wastewater and managing aquifers for withdrawals. Water accounting calculates whether these solutions genuinely augment supplies and help to bridge shortfalls or whether they simply constitute a "sleight-of-hand" – shifting supply from one time slot to another or from one user (often the environment) to another without those shifts being made transparent, evidenced and sanctioned by public/policy agreement.

Rising water demand, water scarcity and water competition

Rising world population and urbanization, coupled with a growing demand for food and the need to secure environmental flows,[5] have led to increased demand for water (Green *et al*., 2015; FAO, 2012; Amarasinghe and Smakhtin, 2014; CAWMA, 2007). This rising demand, set against a fixed (though increasingly variable) supply set by the global hydrological cycle, gives us water scarcity. Water scarcity in turn leads to higher competition among different users of freshwater. Managing this competition by distributing available water between users is a major water governance challenge. Water accounting informs policy-makers as to whether interven-

[5] Environmental flows provide for the healthy functioning of freshwater bodies such as rivers, wetlands and deltas.

tions (such as new dams, irrigation schemes or water law reform) will materially assist in managing water scarcity and competition.

Water variability – dealing with water shortages

Climate variability aggravates water scarcity, with climate change-induced variability expected to increase (Schewe *et al*., 2014) and extremes likely to be more frequent and severe. Droughts are examples of water variability and recent cases show their impact on urban areas surrounded by irrigated agriculture (e.g. Cape Town, Los Angeles, rural villages in the Sahel). In many cases, droughts in agricultural and urban areas have led to over-pumping aquifers, resulting in severe land subsidence and affecting infrastructure and the capacity of aquifers to hold water (e.g. Mexico City) (Galindo-Castillo *et al*., 2017). In developing and transitional economies, drought can lead to famine, death, migration and even political and social disorder (Obokata, *et al*., 2014; von Uexkull, 2014). Water accounting during droughts calculates how much water remains in stocks and flows, and what new supply- and demand-side measures will further stretch resources. Combined with foresight studies, water accounting can help prepare for climate shocks (Briggs, 2017).

Water variability – dealing with flooding

While water scarcity is the focus of this White Paper, flooding cannot be ignored. Flooding is a major stressor for urban and rural communities and on water infrastructure designed for old hydrological regimes. Importantly, flood events can also provide an opportunity for water supply augmentation if infrastructure to control and store excess water can be designed, built and operated (Ehsani *et al*., 2017; World Bank, 2016). New approaches to accommodate floods, the benefits of floods, and potential trade-offs linked to new infrastructure will depend on accurate water accounting.

Improving water productivity in all sectors

With rising population, food, fibre, fuel and feed demands, it is essential to achieve optimal levels of water productivity, production and efficiency of water use in urban, agricultural and industrial systems (CAWMA, 2007). In agriculture, the goal is to manage water and other inputs (e.g. soil, farm technology and labour) so that crop yields are optimized for a given context and set of constraints (Giordano, 2017). Water accounting contributes to these debates on the relationships between productivity, efficiency and water withdrawn and consumed.

Managing allocation in river basins with irrigated agriculture

The large amount of water withdrawn and consumed by irrigation in many tropical and subtropical basins, combined with other demands such as water for cities, sets up a key water allocation and water accounting challenge: how to reduce or cap water consumption within irrigation while increasing food production in ways that do not undermine river basin resilience (World Bank, 2007; CAWMA, 2007). It is worth noting that basin water accounting partly evolved from dealing with this issue, because of the concern that field-level efficiency savings would paradoxically lead to higher consumption (Berbel, 2015). Another significant water accounting question applies to the recommendation (Rockström *et al*., 2010) to increase water

supplies to and consumption from rainfed agriculture via supplementary irrigation, a question that can be phrased as: "What impacts will this have on downstream users?" Water allocation in irrigated and rainfed river basins remains a major challenge, especially if new supply-side solutions (e.g. dams) are limited.[6]

Managing the increasing interconnectedness among users

The small gap between supply and demand found in many river basins and aquifer systems increasingly links water users to each other. The lack of a buffer means that any allocation and consumption of water by one user automatically takes water away from another user (even over great distances). Any rise in such trade-offs requires careful monitoring and accounting in order to maintain or enhance economic growth, protect basic needs and boost transparency to remove a disproportionate sense that water is being "stolen" by a user.

Interconnectedness is expressed via the rise of corporate interest in water scarcity over the last ten years. Fearful of "stranded assets" (Whelan and Fink, 2016) – for example, when a bottling plant can no longer secure water from its vicinity – companies have engaged with water in a number of ways. Many have joined international efforts at water stewardship, undertaken water risk and footprint analyses, and acted on these analyses to reduce their risk of water shortage (Hepworth and Orr, 2013; ICMM, 2017).

Distributing water more equitably and with better timing

The productivity of irrigation systems and well-being in urban centres will respond to more timely and more equitable distribution. Nearly all human, natural and human-caused processes benefit from clean, fresh water, delivered on time. Water accounting within these domains informs that distribution process and can cumulatively result in being more efficient and productive.[7]

Managing the water-energy-food nexus and other trade-offs

Water is one critical part of the nexus connecting energy, land, environment and food (ADB, 2013). The connections among these mean that changes to water availability can have unintended consequences for other parts (Scott *et al*., 2011) – for example, unlike gravity irrigation, precision irrigation utilizes energy to pump and filter water. Water accounting shines a light on these connections and trade-offs.

Reducing negative environmental costs

A key environmental risk of water scarcity and excessive demand is the lack of environmental flows, also known as ecological flows, for rivers, wetlands and deltas. Water accounting determines the size of these flows and associated properties such as depths of flows, timing and temperature, in order to advise how these instream and consumptive components are integrated into water allocations.

A second environmental risk is that of water pollution. Water pollution (arising from point spills from factories or from diffuse sources such as fertilizer spread over

[6] In some situations, the scope for reducing irrigation demand may also be limited.

[7] Connections between time, timing and efficiency are explained in Lankford (2012).

farms) not only makes freshwater unusable and adds to clean-up costs, it also makes water allocation more problematic. This is because water is required to dilute pollution to acceptable levels. While this dilution demand is difficult to quantify and account for, it further shrinks further the space between water supply and demand.

A third environmental externality is atmospheric, involving greenhouse gases such as: a) carbon dioxide produced when water technologies switch to carbon-intensive energy sources; and b) methane generated by rice irrigation and livestock. While some emissions are difficult to reduce, other are associated with technological choices that attempt to reduce water demand. Water accounting helps draw out these connections.

Accommodating the effects of non-water policies

In areas with limited water resources, non-water policies arising from elsewhere in the economy can alter the balance of water demand (World Bank, 2007). An example is where a policy to increase food security in a semi-arid region by irrigating during the dry season puts additional pressure on already limited surface water resources. Alternatively, there are also many options for reducing water consumption by switching economies out of irrigated agriculture towards light industry or the service sectors (Allan, 1993, 2012). Water accounting can help model these scenarios and reveal how they affect the balance between water supply and demand.

Water roles are changing rapidly

Water accounting is responding to and reflecting the changing roles within water management and governance. Corporations, charities/NGOs, utilities and water user groups are more involved in issues of water than ever before (Hepworth and Orr, 2013; Newborne 2012) while at the same time governments are looking for ways to shed responsibility and shift to light-touch facilitative and regulatory roles. However, major problems arise from these changing roles. Some questions to be asked are: "How do current arrangements of infrastructure and institutions support these new roles?" (Soliev *et al*., 2017) and "How are these roles conjoined to create sufficient oversight rather than gaps?" In other words, how might state-owned and operated infrastructure share operational data and decision-making with the private sector and user groups (NRC, 2012) and vice versa? And how can state agencies access water data from the private sector and user groups?

Global interest in water accounting is growing

Water accounting is on the increase, as seen from these examples:

- India is developing a blueprint for national water accounting (Schmidt *et al*., 2017).
- South Africa has started to incorporate ecosystem services accounting in its national statistical records.[8]
- Since publishing its 2013 policy paper "Thinking about Water Differently," the Asian Development Bank has promoted water accounting to evaluate its supply and demand management policies (ADB, 2013).

[8] https://seea.un.org/es/news/inception-mission-south-africa-natural-capital-accounting-and-valuation-ecosystem-services

- With its long history of water accounting in the Murray-Darling basin, the Australian Water Accounting Standard is hosted by the Australian Bureau of Meteorology (BOM, 2017).
- The Public Policy Institute of California recommends that water accounting be adopted to manage water before and after the current drought (PPIC, 2016).

While these trends in water accounting are positive and to be welcomed, much more can be done to systematically support water accounting.

4. WATER ACCOUNTING CHECKS ENVIRONMENTAL AND WATER ASSUMPTIONS

Understanding the multiple causes of environmental change is not easy (although sometimes it may appear easy because we quickly invoke causes that align with our favourite concerns). For example, a drying river can be ascribed to several causes: climate change, deforestation, afforestation, excessive and/or inefficient irrigation, shrinking wetlands, and soil and vegetation changes caused by too many cattle. Only well-researched evidence can determine the weight given to any of these factors. Without evidence, our explanations of environmental change are nothing more than assumptions, or myths.

To understand the causes of the drying up of a river needs thorough long-term research conducted at both local and basin scales. This photo shows a gauging station on the Great Ruaha as a part of hydrological studies to research environmental change. (SMUWC, 2000; Kashaigili *et al*., 2006; Lankford *et al*., 2004).

Busting myths through environmental change studies

Properly executed and cross-checked, water accounting is an important way to expose environmental and engineering assumptions that seem plausible (e.g. that irrigation wastes water) but may need greater scrutiny. For example, basin water accounting double-checks irrigation policies that promote higher efficiencies through the adoption of drip irrigation without considering the consequences of increased water consumption that can come from higher efficiency (e.g. if losses of water from irrigated farms switch from being recovered to being consumed) (Molden and Sakthivadivel, 1999).

Other plausible environmental and engineering narratives analysed by rigorous quantitative water analyses include some commonly assumed supply-side thinking regarding dams, forests and wetlands (e.g. that they all

boost water supplies). A sample of assumptions is given in Table 1. In nearly all cases, water accounting reveals that accurate computations and observations improve knowledge over existing stories that often take a partial view of a phenomenon. For example, afforestation might beneficially improve soil-water infiltration rates but negatively affect and reduce (via increased perennial deep-rooted water transpiration) the amount of water moving from the soil into groundwater, with the result that some forests are not water producers but become net consumers of water.

How are water assumptions unpacked by water accounting?

Water accounting is useful in addressing assumptions about environmental and hydrological change. It can systematically explain patterns of water supply, demand and distribution. Useful, accurate and objective water accounting can be traced to the following principles:

Water accounting obeys the law of conservation of mass in correctly calculating a water balance. For example, water is fully accounted in a river basin by distinguishing between withdrawals for consumptive and non-consumptive uses, and considers how 'water losses' might be permanent or temporary (Karimi *et al*., 2013).

Water accounting is tailored to spatial and temporal scales. When applied to problem-solving, water accounting defines its hydrologically relevant spatial domain (e.g. watershed, basin), but also artificial/infrastructure systems (e.g. irrigation, city), if inflows and outflows are known or measurable. Water accounting also defines its temporal domain (e.g. calendar year, type of hydrological period). The interpretation of data changes as the scales change.

Table 1. Environmental and engineering myths and assumptions unpacked by water accounting

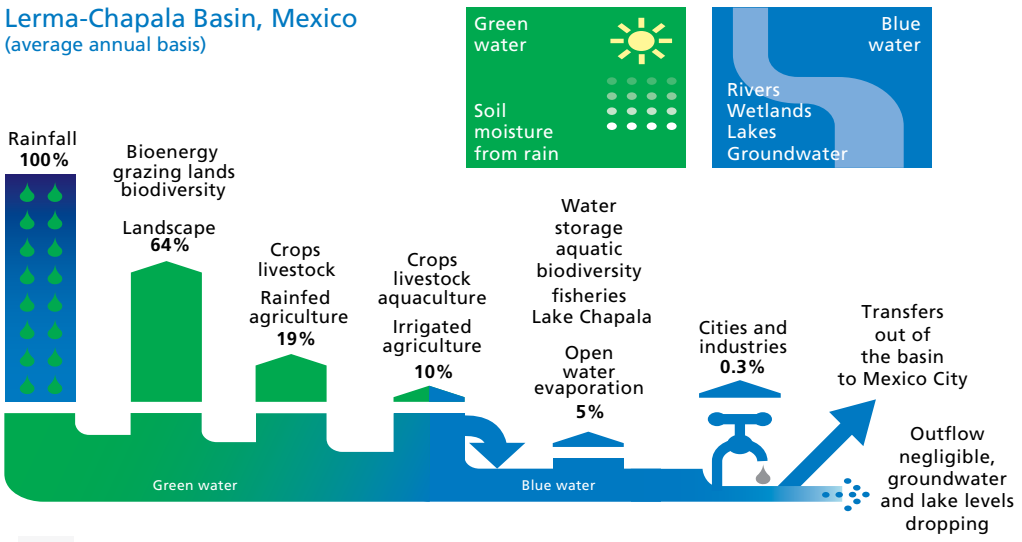
Plausible myth / assumption	How water accounting can show a more accurate story	Further information
Drip irrigation saves water and reduces consumption.	Farmers, responding to the savings produced initially by drip can change, extend and increase their cropping using those savings. This new cropping results in more water consumed at the irrigation system level. Drip does save water but farmers often consume those savings by increasing their area under irrigation.	CAWMA, 2007; Ward and Pulido-Velázquez, 2008; Batchelor *et al*., 2014; Richter *et al*., 2017.
Healthy wetlands act as a sponge and increase water supply.	Wetlands attenuate river flows and can support base flows during drier periods and can help recharge aquifers. However, annually and volumetrically, wetlands evaporate water and can act as net consumers of water. The hydrology of wetlands is specific to circumstances, rainfall events and the nature of change of the wetland.	Acreman and Holden, 2013; Dietrich *et al*., 2014.
Forests act as water towers and increase water for streamflows.	Forests act on catchment hydrology in different ways depending on the type of vegetation, net transpiration and effects of rooting on soil infiltration rates. In South Africa, for example, some forests, which are especially composed of alien invasive species, are net water consumers and are removed or thinned.	Calder, 1998; Wang and Fu, 2013; Le Maitre *et al*., 2016; Poulos, 2018;
Upstream irrigation causes downstream shortages of water that reduce hydropower generation.	The filling and draw-down of dams depends on many factors, not only changes to runoff caused by upstream irrigation. The volume of water held in dams is often surpassed by the volume of water generated during monsoonal events by large catchments.	Kashaigili *et al*., 2006.

Dams increase water supplies.	Dams need to be positioned, sized and operated according to a number of criteria. In highly evaporative semi-arid climates, these same design criteria can limit the usefulness of dams in supplying water downstream. Dams that are undersized in relation to downstream needs or to climate variability, or that are poorly managed (e.g. stored water is over-released), are "constrained" in their ability to meet water needs during dry periods.	Aberra, 2004; Kull, 2006; Kashaigili *et al*., 2006; Venot *et al*., 2011; Cole *et al*, 2014.
Rainwater harvesting creates additional water and "greens" semi-arid catchments.	Carefully designed, positioned and maintained rainwater harvesting can improve the seepage of rainfall into soils and groundwater in situ. But water captured by rainwater harvesting in upstream parts of a catchment can deplete water from downstream uses and cause problems for potable water supplies. Rainwater harvesting potentially shifts water consumption upstream, a phenomenon that needs to be discussed by all catchment stakeholders.	Batchelor *et al*., 2002; Glendenning and Vervoort, 2011; Bouma *et al*., 2011.

Water accounting methods are applied to problems. The selection of water accounting methods is rarely straightforward as they must fit the problem and context. Where applicable, water accounting is multi-sectoral and looks at multiple uses of water, including the environment. Furthermore, quantitative water scientists, engineers, and professionals must work closely with managers and policy-makers to ensure that analyses address real-world problems rather than the protocols of the quantitative method (FAO, 2016).

Water accounting communicates. To foster debate, tackle embedded myths, and create new understanding, water accounting must be communicable and easy to digest. To quote the Water Accounting Plus (WA+) website: "*WA is the process of communicating water resources related information…*" One example, is the use of 'finger diagrams' for basin water accounting which clearly show how water is consumed by different sectors and uses (Figure 1). Communication of water accounting is the remit of water reporting "*Reporting concerns the presentation of water balance information in formats tailored to the needs of various reporting uses and users*" (MCA, 2012).

Figure 1. Using a finger diagram to communicate water allocations



Source: CAWMA, 2007

5. WATER ACCOUNTING INFORMS WATER GOVERNANCE AND SUSTAINABLE DEVELOPMENT

Water accounting and reforming water governance

Water governance reform can take place via direct auditing of governance; and/or being informed by water management practices. Water accounting is part of both pathways.

Water accounting for water auditing and governance

Water accounting informs water governance by analysing whether a given domain is sustainably using water within the limits of the hydrological system. A case study that illustrates these connections by drawing attention to the failure to conduct water accounting, unsustainable water management, and air pollution can be found in Delhi, the capital of India. Box 2 describes how a lack of water accounting and water governance allows electricity for groundwater use to be available at zero or low cost, leading to weak regulation and overexploitation of withdrawals from groundwater. One surprising and partially related consequence is that this intensive cropping system is also characterized by burning crop stubble, contributing to other sources of air pollution in nearby Delhi. Water accounting would draw attention to the overuse of groundwater and begin the process of discussing how to manage energy, land, water, and farming practices with a view to restoring both groundwater and air cleanliness.

Box 2. The Cost of Not Accounting Groundwater

Water research shows that overmining of aquifers can be traced to various factors within the political economy of India (Shah, 2009; Wyrwoll, 2012). Access to subsidized electricity has promoted unsustainable water consumption in North India in order to grow rice and wheat. Because politicians don't act on these findings, water is withdrawn to feed an intensive cropping system. One unexpected environmental cost is that air pollution has also increased. Every October, Delhi becomes the smog capital of the world because, to prepare their fields quickly for sowing winter wheat, farmers burn rice stubble. Widespread respiratory diseases and health impacts for city dwellers provide further reasons to call for the full accounting of groundwater, the calculation of power subsidies and the characterization of intensive farming.

(Communication from Sahdev Singh, ICID, 2018)

Table 2 outlines cases in which water governance policies have engaged with sustainable water use as a result of water accounting. Most of these cases describe long-term and complex problems, and because policies are not quick to change, much of this work is ongoing. Based on information from Box 2, Table 2 and other material, water accounting supports water auditing and the reform of water governance via many different pathways.

Water accounting quantifies unsustainable or inequitable practices and trends. Water accounting identifies how existing water withdrawals and consumption are defined as unsustainable by exceeding natural inputs via rainfall, groundwater recharge or other means. Water accounting can also determine whether sectors, countries or users are equitably provided with water.

Water accounting defines target levels of sustainable withdrawal and consumption of water. Water accounting will often recommend lower levels of water consumption that match natural recharge or renewable resources available, including safety margins.

Water accounting assesses the sustainability trajectory of the domain. Water accounting can determine if a domain is moving towards a less or more sustainable future. Water accounting can map changes over time in drivers that create water demand, such as area, density and technology.

Water accounting defines transition pathways. Water accounting will quantify which parts of the hydrology of the domain need to change if the domain is to transition from being unsustainable to sustainable. Water accounting provides information on the hydrological consequences of different supply and demand management scenarios that can support dialogue.

Water accounting identifies physical environmental factors that cause or help drive hydrological change. Water accounting will attempt to explain what is causing hydrological change – for example, climate change, deforestation, urban growth and so on.

Water accounting combined with water auditing helps to unpack the political economy of water, which in turn affects how water governance is designed. The case described in Box 2 on low pricing of rural electricity exemplifies how a political decision to protect an agrarian voting constituency drives unsustainable withdrawals from groundwater.

Water accounting supports water management, which feeds into water auditing and governance. This important connection is further addressed in the next Section.

Table 2. How water accounting supports water governance reform

Case	What was the water governance problem?	What information did water accounting provide?	What governance advice was generated or how did water policy change?	Further information
USA, Nebraska aquifer	Excessive and unsustainable water use from aquifer to support irrigation.	Correct analysis of sustainable yield of aquifer and annual consumption by irrigation.	Introduced water meters, regulated withdrawals, created water user groups and self-monitoring.	Bleed and Hoffman Babbitt, 2015; Scanlon *et al.*, 2012.
China, North China Plain	Excessive and unsustainable water use from aquifer.	Analysis of aquifer yield and annual consumption by irrigation.	Regulation of land use under irrigation, changes to irrigation technology, shortening the irrigating season length.	Kendy *et al.*, 2003; IWMI, 2006.
USA, Arizona aquifer	Excessive and unsustainable water use from aquifer.	Correct analysis of sustainable yield of aquifer and annual consumption by irrigation.	Water banking via managed aquifer recharge. Investment in this approach by one public entity–the Arizona Water Banking Authority–has exceeded USD 350 million.	Megdal *et al.*, 2014.
Thailand	Uncertainty over water consumption for different sectors in different basins.	Revealed the water consumption of different future economic scenarios to aid ministerial planning.	No policy change as yet; for information only.	Sriwongsitanon *et al.*, Unpublished (with IWMI)
Ghana, Volta River	Uncertainty over water consumption for different sectors in the Volta River.	The quantification of green and blue water linked to land use to identify potential sources of water saving.	No policy change as yet; for information only.	Leh and Rebelo, 2018.
Italy	Excessive and uneven consumption by irrigators.	Volumetric assessment of water withdrawn and consumed by farmers.	Application of user-pay principles to volumetric water to curtail unwarranted withdrawals for agricultural water.	Zucaro, *et al.*, 2015/16
Australia	Allocation of water in the Murray-Darling basin.	Revealed more accurate picture of withdrawals and consumption by different sectors to support market-based allocation.	The water utility uses information from the accounts to help explain water allocation and use in various sectors along the Murrumbidgee River and inform ongoing debate.	BOM, 2017.
Indonesia	Regulation and management of the Brantas River Basin.	Volumes of water withdrawals and allocations.	Application of pricing incentives in water markets to regulate water demand.	Rodgers and Hellegers, 2005.
Russia (all major basins)	Lack of knowledge about water volumes for use.	Identifying basins that: a) were prepared for climate-induced variability; and b) had spare water for further development.	Advice on demand and supply-side reforms, including instruments such as interbasin transfers.	Danilov-Danilyan *et al.*, 2014; Georgievsky, 2016.
Turkey	Performance of irrigation systems transferred to farmers from government.	Performance indicators of irrigation systems; cost recovery for operation and maintenance; area irrigated.	No substantial increase in performance was seen; the authors concluded that ongoing support to farmers is needed.	Burak, 2013.

Water accounting for managing water

Water accounting includes quantitative methods that inform the day-to-day management of water to achieve desired outcomes and performance levels. Boxes 3 and 4 briefly introduce two case studies showing how metrics from water infrastructure systems in southern Italy and Brazil enable different organizations and regions to discuss how water is shared between users, including farmers.

Box 3. Best Practice for Drought Management in southern Italy

Proper use of water resources has always played a crucial role in the socio-economic development of southern Italy. In recent years, the problem of sharing water resources among neighbouring regions in Italy has increased. This is why the Government issued a "Programme Agreement on Shared Water Resources" (ex art.17, L.36/94) between Basilicata Region, Apulia Region and the Ministry of Public Works. This agreement enabled the quantitative assessment of water resources between Basilicata and Apulia Regions, in order to plan different uses, generate plans and activities to manage water scarcity, assess costs for different uses and define adequate prices and tariffs

(Arcieri, 2016)

Box 4. Managing Irrigation in Brazil

A pioneering project, the Irrigation Advisory Service, was developed in northeast Brazil. The main goal of the project was to create and transfer information about irrigation performance to farmers. At the beginning of the project, on-field irrigation application uniformity was close to 67 percent. After corrections were made to the systems, uniformity reached 85 percent. Energy use was also monitored and lowered. Information was passed to and from farmers using SMS and web-based services

(Corcoles *et al.*, 2016)

Water accounting includes a set of methods to monitor water supply and usage on a regular basis to create measures of performance such as productivity, efficiency and equity (see Table 3). Often specific to the system they are designed for, water accounting methods, data types and indicators assist water management in a number of different ways. Water accounting:

- Provides real-time or up-to-date information on the status of supply and demand for water (Hong *et al.*, 2016).
- Offers transparency to users; information can be used to benchmark performance over time or compare peer-to-peer performance (Yakubov, 2012).
- Provides seasonal summaries and reveals where constraints and gaps in operation, maintenance and design exist (Alcon *et al.*, 2017; Naik and Glickfield, 2017).

- Depends on, but also generates, advances in information technology to manage and operate infrastructure systems (Choi, 2016; Navarro-Hellín *et al*., 2016).

Table 3. Water accounting indicators for managing infrastructure

What system data is gathered?	What management indicators can water accounting provide?	How is this information used in water management?
Agrometeorological data (rainfall, evaporation).	Productivity (kg/ha or kg/cubic metre of water or $/ha or $/m3).	Compares production to benchmarks and identifies which inputs constrain production.
Hydrometric data (stream flows, canal flows, drain flows, quality).	Efficiency (volumetric % water target) or timing efficiency (e.g. hours of delay)	Reveals how losses might affect timeliness or explain poor uniformity of water supply.
Inputs data (area, energy, soil, labour, agrochemicals, materials).	Equity and uniformity (Many measures examine uniformity – e.g. the coefficient of variation).	Determines how the variability of supply and demand is spread between users or geographic regions. Higher uniformity benefits efficiency and productivity.
Production data (crop types, yields, planting schedules, prices.)	Adequacy (% flows or % area, or % households above a given threshold).	Measures of coverage can be used to compare with previous years or between peers.
Economic data (prices, costs).	Associated input ratios (e.g. energy per ha or per farm).	Helps to determine costs for different inputs in relation to each other.
Rainwater harvesting creates additional water and "greens" semi-arid catchments.	Quality (e.g. salinity, agro-chemicals, pathogens, biological oxygen demand).	Determines treatments and/or dilution ratios needed to bring water quality to satisfactory levels.

Sources: Murray-Rust and Snellen, 1993; Plusquellec *et al*., 1994; Playán and Mateos, 2006; CAWMA, 2007; Pereira, *et al*., 2012; Lankford, 2012; Soto-García *et al*., 2013; Onda, *et al*., 2012.

On the whole, better-managed domains and systems (e.g. irrigation, urban, industrial) build a virtuous circle that connects monitoring, data and knowledge about water performance with other institutional, operational and management outcomes, including environmental sustainability, personnel and financial management, and the ability to modernize water control (FAO, 2004; Freeman and Burt, 2009). And the opposite also applies; water systems can be trapped in a vicious circle of poor performance accompanied by a lack of water knowledge about the system.

In turn, the operational-performance circle described in the previous paragraph supports a second connection between reform of water governance and the likelihood of its success. Well-performing systems make those systems more open and amenable to significant new arrangements of water governance (e.g. transfer of ownership, new licences, application of pricing structures).

Water accounting for the SDGs

The SDGs for water and water-related sectors such as food require the development of indicators to monitor progress. As Hák *et al*. (2016) state: *"Meaningful indicators are most needed to assess sustainable water use for humans and natural systems considering both quantitative and qualitative aspects."* Drawing on Merrey (2015), IWMI (2014) and Bhaduri *et al*. (2016), water accounting supports the formulation and use of indicators for the SDGs (especially SDG 6, related to water, see Box 5) in a number of ways:

- Water accounting informs a debate about the relevancy of indicators that report on the SDGs, including numerical data such as the number of households with improved water supplies and ratio data regarding the efficiency of systems.
- Water accounting feeds into the discussion on the design of indicators that most commentators agree need to be SMART.[9]
- Water accounting provides baseline information about domains which can be used to identify changes resulting from new policies.
- Water accounting reveals where information is missing, unreliable or can be derived from other metrics (e.g. land statistics).
- Because of its rigour in examining water from a quantitative perspective, water accounting supports a uniform approach to monitoring the SDGs.
- Water accounting helps highlight and address possible trade-offs in the SDGs by using a long-term water-energy-food nexus perspective. For example, the need to achieve food security (SDG 2) could potentially lead to overconsumption of water, tipping catchments and aquifers towards greater water scarcity and inflexibility. The same risk applies if SDG 7, on energy, is met via access to solar renewables, since freely available electricity could lead to more water being withdrawn, undermining the sustainable achievement of SDG 6.

In summary, water accounting brings realism and rigour to the discussion around monitoring the water and water-related SDGs. While the SDGs represent the most comprehensive international framework for delivering sustainable development to the world's economies and societies, they are fraught with risks in terms of monitoring progress. Indicators are too easy to extrapolate from remote sensing or from unreliable statistics, or are not fully understood in terms of theory. Without the thoroughness offered by water accounting, the consequence will be that policy-makers won't manage water and water-related SDGs – but rather will manage the indicators.

Water accounting for sustainable economic growth

The growth of economies experienced in villages, towns, regions, and cities provides significant societal benefits including job creation, human well-being, and wealth and tax generation for further expenditure on schools, medical facilities, recreational spaces and transport. However, economic growth can create an additional water demand above and beyond the current levels.[10] Water accounting can help public

[9] SMART criteria: Specific, Measurable, Achievable, Relevant, Time-bound (see IAEG-SDGs, date unknown)

[10] Note that economic changes can also reduce water demands by shifting from high to low consumptive uses (e.g. from irrigation to services or light industry)

Box 5. SDG Goal 6: Ensure Availability and Sustainable Management of Water and Sanitation for All

6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all

6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation, as appropriate

6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

6a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

6b Support and strengthen the participation of local communities in improving water and sanitation management

planners and corporations to hydrologically cost their plans to ensure that they are not stranded in the future without water, taking water from existing local users or creating water shortages elsewhere.

Examples of balancing economic growth with water growth are given in Table 4. The Texas State Water Plan for 2017 succinctly summarizes the problem (urban growth in Texas is among the fastest in the USA):

> *"To ensure the ongoing vitality of our economy, Texas' citizens, water experts, and government agencies collaborate in a comprehensive water planning process. We plan so that Texans will have enough water in the future to sustain our cities and rural communities, our farms and ranches, and our homes and businesses while also preserving the agricultural and natural resources that have defined Texas for generations. The 2017 State Water Plan tells us that our population will continue its rapid growth. The plan also provides a roadmap for how to address the water needs that accompany that growth by identifying water management strategies and their associated costs for communities all across the state. The information in this plan is critical to ensuring that Texas has adequate and affordable water supplies both now and in the future" (TWDB, 2017).*

In this example, water accounting provides a much-needed quantitative assessment of how the Texas Water Plan can be 'hydrologically costed', especially when Texas faces drought conditions, as explained on page 69 of the Plan (TWDB, 2017): "To ensure that planning groups did not assign more water supply to a water source than the source could provide in a drought, the TWDB performed a detailed, statewide accounting of all assigned existing water supply volumes and notified planning groups of over-allocation."

Partnerships for water accounting

Future successful water accounting will depend on a healthy collaboration among many stakeholders drawn to the benefits of sharing risks and approaches (Baleta and Winter, 2017). Successful water governance reform and accounting are dependent on full inclusion of all water actors, working within an unbiased open forum, to contribute to problem, method, analysis and solution identification. Future progress will require that protagonists of the different systems of water accounting agree on methods, measurement, metrics and terminology (Chalmers *et al*., 2012; Konar *et al*., 2016).

Table 4. Selected examples of water accounting for sustainable economic and population growth

Case	What is the problem?	Role (or potential role) of water accounting	Further reading
Chennai, India	Along with many other major cities in India, the population and water demand of the population of Chennai is growing significantly.	Demonstrating current limits of supply to meet only 75% of demand.	Times of India; https://thewaternetwork.com/article-FfV/indian-water-treatment-market-growth
Idaho Falls, USA	Finding enough water for urban growth: "To anyone watching the statewide discussion of water resources, it is no surprise to hear me say that water concerns are real. This is a time of transition for our state. Fresh, potable water is key for city development and growth. Idaho's cities are challenged to obtain enough water for growth while not infringing upon water needed for agriculture. Idaho Falls is right smack dab in the middle of this statewide conversation."	Defining where this extra water will come from – including interbasin transfers and groundwater. Ruling out intersectoral allocation limits options available to cities in Idaho.	http://www.localnews8.com/news/idaho-falls/mayor-casper-delivers-state-of-the-city/684761980
Mexico City	Unparalleled growth in population of Mexico City leading to water security problems for city inhabitants; high incidence of water pollution and depletion of groundwater.	Affordability of water as a percentage of total monthly income; trends in groundwater levels and contamination.	Galindo-Castillo *et al*., 2017. https://progrss.com/policy/20170718/revenge-tlaloc-water-crisis-mexico-city/.
Beijing City, China	Like Mexico City, very rapid growth of Beijing City is putting considerable pressure on water resources but, unlike Mexico City, groundwater is being recharged.	Revealing the extent to which groundwater is being recharged within the urban area.	https://eos.org/research-spotlights/modeling-beijings-water-crisis

East Anglia, UK	East Anglia is experiencing some of the United Kingdom's highest population growth. A major utility, Anglia Water, has to sustain water provision for growing needs.	Revealing where supply and demand management solutions are needed and the limits to transferring water out of the region to Greater London.	AW, 2015.
West Asia	Factors driving water conflicts in Jordan, Syria, Egypt, Yemen, Iraq and Iran; climate change, including a constant decline in rainfall; rising populations; the [rapid pace of] industrialization; a rise in standard of living ... and worrying patterns of water consumption.	Isolating potentially causal factors behind increased water consumption; providing metrics feeding into regional diplomacy and discussion.	https://en.mehrnews.com/news/130396/Water-diplomacy-most-pressing-matter-in-West-Asia

6. CONCLUSIONS, RECOMMENDATIONS AND MESSAGES

This White Paper, aimed principally at policy-makers, is designed to stimulate interest at the highest political level in water accounting, its vital role in improving water resources management, and how this supports the Water Goal, SDG 6, and the whole of the UN 2030 Agenda for sustainable development.

The paper reviews the growing interest in water accounting, what it is, why it is needed, and equally important, how it can be put into practice. Water accounting quantifies water resources and uses of water, much like financial accounts do. Like financial accounts, they do not contain qualitative judgements, this is part of water auditing. Water accounting is not a new idea, yet it is an alarmingly simple one. It is based on the premise that *'We cannot plan and manage what we do not measure'* – a statement that few would disagree with.

But given the current focus on water as a precious and limiting resource, the risks of extreme floods and droughts, and water's central role in the 2030 Agenda, it is difficult to understand why so little attention is paid to water accounting and to making sure we have enough water. Reports from South Africa (January 2018) suggesting that Cape Town may be the world's first major city to face the prospect of running out of water following severe drought, is a timely 'wake-up call' for everyone to focus on accounting for water.

Society needs more accurate answers to the key questions posed in this review. Much more data is needed, but simply doing more, or more accurate, water measurements and assessments is not enough. Water accounting per se is of little use. But as a tool for understanding and resolving water problems and supporting water management, it has immense value. Water accounting provides the essential foundation for good water governance, which is widely recognised as the major weakness in water resource management in most developing countries. What makes water governance so particularly challenging is, according to the World Bank[11], the *'uncertainty about the amount and quality of water available from year to year, in terms of both stocks and flows'*. This is where water accounting fits into water management.

But how does water accounting connect with water governance? The answer lies in water auditing. This review introduces this as the means of placing the findings, outputs, and recommendations of water accounting into the broader societal context of water management, water supply, and water services delivery.

[11] World Bank (2006), Good governance for good water management.

Together water accounting and water auditing support good water governance and in turn this supports sustainable development.

Many complementary benefits flow from this:

Water accounting and auditing together, can improve understanding of the 'hydrological cost' of sustainable development; the level of water governance needed to deliver sustainable water services; and the water implications of delivering and achieving 17 SDGs – the means of implementation.

Water accounting is of necessity inclusive and brings together different water users from different backgrounds, cultures, and levels of education. It can create a common 'water' language among them and avoid confusion over such issues as 'water use' and 'water consumption'. In the UK for example, communication barriers exist between water companies that plan water use in megalitres per day, and farmers who assess irrigation water needs in acre-inches per crop season. Creating common ground helps water managers and stakeholders to better understand each other.

Water accounting can help to identify common and cross-sector water problems. Organisations that tend to work in 'silos' often influence and shape their problems with little regard to how it affects others. Working together enables everyone to address problems collectively, achieve consensus, and establish resource needs and data requirements for more evidence-based solutions.

Water accounting can improve transparency over water allocations in a basin or aquifer and also enable stakeholders to challenge policy-makers to adopt sustainable solutions that may be at odds with short term voter, legal, fiscal interests.

Water auditing enables water accounting to inform debates about regulatory, ownership, and management roles of public, private, charitable, and water user organizations.

Whilst water accounting depends on data collection, it can also determine what data are needed for an account that is 'fit-for-purpose'. More data collection will not automatically prompt better water governance outcomes. Deciding what data to collect and how it is collected, in field or through Earth Observations must be an integral part of any water accounting method.

The way water is governed determines the usefulness of water accounting. Water accounting can improve water governance, but the reverse is also true. Systematic and meaningful approaches to institutional and infrastructural reform will make water accounting more relevant and central to these efforts. In simple terms, a more substantial push for better water governance will pull water accounting along with it.

Water accounting alone cannot resolve the problems of water governance, but it can go a long way to improving and reforming governance by providing the information needed to support sound decision-making.

The main recommendations and messages coming from this review are about adopting water accounting and supporting its development.

Reasons for adopting water accounting

Building sustainable development

Policy-makers who adopt water accounting can make a significant contribution to sustainable development. This would ensure that plans and related SDGs are monitored and 'costed' in terms of how much water they use or consume by asking the question "How much water will this plan need, and can it be met from existing supplies?"

Resolving conflicting water allocations and trade-offs

The role of governments is changing to one of providing regulatory and oversight services. This role of "honest broker" will need evidence provided by water accounting to manage excessive and conflicting water demands and negotiate trade-offs.

Preparing for drought and emergencies

Water accounting can support drought preparedness. River basins and their populations face increasing risks of drought which can result in starvation and death for impoverished people, and seriously harm economic output, and natural ecosystems. 'Monitoring and early warning' is one of three pillars recommended for drought policy, planning, and preparedness. Water accounting underpins this pillar. It enables vulnerability to drought and its impact to be assessed and it supports evidence-based decision-making for mitigating drought impacts and responding to short, medium, and long-term emergencies.

Examining infrastructure and institutions

Infrastructure and legacy water laws, prices, rules, and tenure determine who gets what water in a river basin, especially when there is water shortage. Water accounting provides transparency for how water allocations are made and how trade-offs are addressed for improved water governance.

Asking questions of water professionals

Policy-makers see the world from an investment and intervention point of view. With water accounts available they can task water professionals with questions that facilitate sustainable development and help solve water-related problems, such as how to save water in different sectors? and will a dam or groundwater development improve water supply and who benefits?

Supporting water accounting

Policy-makers can also take immediate and practical steps to support adoption and expansion of water accounting services and skills.

Checking water accounting capabilities

Policy makers should recommend water accounting focal points are established in-country and related skills strengthened as a service within all water related go-

vernment departments. This should go together with a review of current water accounting facilities, especially those for public-good problem-solving, such as water allocation in river basins and from aquifers.

Funding hydrological data collection and analysis

Governments, as a matter of priority, must invest in more high quality data collection as the basis for effective water accounting. A significant gap in many countries is the lack of hydrometric infrastructure (e.g. gauges) at field and basin levels to gather hydrological basic data, such as rainfall, evaporation, groundwater levels, and river flows. Data is also needed on water demand from agricultural, urban, industrial, and environmental sectors.

Sharing hydrological data and information

Hydrological information must be shared to so that stakeholders have better oversight of water issues. Too often it is treated as a strategic asset which cannot be shared with scientific organizations, water users, and other third parties. Concealing data, or putting data behind an expensive paywall, contributes to a downward cycle of poor accounting and poor water management.

Sharing water accounting expertise and methods

Sharing water accounting expertise goes beyond sharing water data. There are many organizations working on water accounting from their own perspectives; with 'sharing' only taking place through websites and publications. More collaboration among different water accounting groups and specialists would greatly improve water accounting methods.

Commissioning research

Developments in water accounting in national and international research institutes and universities is not well funded. The need is to establish and expand research units working on different accounting methods including the use of Earth Observation, mobile and basin/field hydrometric sources, as well as from different water using disciplines. Research is needed to map alternative ways of acquiring data, establish common water metrics, and develop methods that better capture the connections among water users, support SDG monitoring, and investigate early warning systems for emerging water risks.

Championing a global centre of expertise

A global centre of excellence on water accounting or a network of centres sharing expertise and working on common projects would benefit all nations and avoid unnecessary duplication of effort and gaps in knowledge. Centres could host different accounting methods, disseminate information; foster debate, and provide 'one-stop-shops' for expertise on water accounting and water auditing. For everyone's benefit, future progress will require that protagonists of different water accounting methods agree on methods, measurement, metrics and terminology.

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WATER ACCOUNTING FOR WATER GOVERNANCE AND SUSTAINABLE DEVELOPMENT

There is growing interest in water accounting, why it is needed, what benefits it brings, and equally important, how it can be put into practice. Water accounting is about quantifying water resources and uses of water, much like financial accounts provide information on income and expenditure. Interest in water accounting is based on the premise that '*We cannot plan and manage what we do not measure*' – a statement that few would disagree with.

Society needs more accurate information and answers to the key questions about water supply and demand. More data are needed but simply doing water measurements and assessments is not enough. Water accounting *per se* is of little use. But as a tool for understanding and resolving water problems and supporting water management, it is invaluable.

Water accounting alone cannot resolve the problems of water governance and managing water resources, but it can go a long way to improving and reforming governance and providing the information needed to support sound decision-making.

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