UN-Water analytical brief

Water-use efficiency

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Contents

Summary

Water use efficiency has been highlighted as a key water indicator in the set of Sustainable Development Goals (SDGs). The method adopted by the SDG is evaluated and compared with specific sector approaches for evaluating the efficiency of freshwater use. The scale of the challenge for the SDG indicator is reviewed and the the range of evaluation methods that can be applied in the major water using sectors is illustrated. A case is made for looking in more detail at operational water accounting procedures in order to evaluate the scope for making the water use efficiency gains anticipated in SDG goal 6. The importance of measuring or estimating evaporative consumption of freshwater and the quantity and quality of return flows is stressed noting that the measurement of these variables in the water balance are often the most difficult to report accurately at scale.

In practice some notable gains in water use efficiency have been made, particularly in the generation of thermal energy, and incremental gains in manufacturing processes and leakage control in municipal water supply systems are evident. The agriculture sector is more problematic. While the adoption of technology, including precision irrigation, has boosted the productivity of agriculture, there is little or no evidence of irrigation water- use efficiency measures 'freeing up' water for other uses or being returned to the environment as recharge or drainage. This is particularly the case in water scarce countries where it is observed that irrigated agriculture tends to 'internalise' efficiency gains through intensification and expansion of irrigated areas.

Determining who will benefit from the adoption of water-use efficiency measures can be done with more precision where spatial planning tools can be deployed, but implementation will need explicit allocation policies to direct efficiency gains to desired beneficiaries.

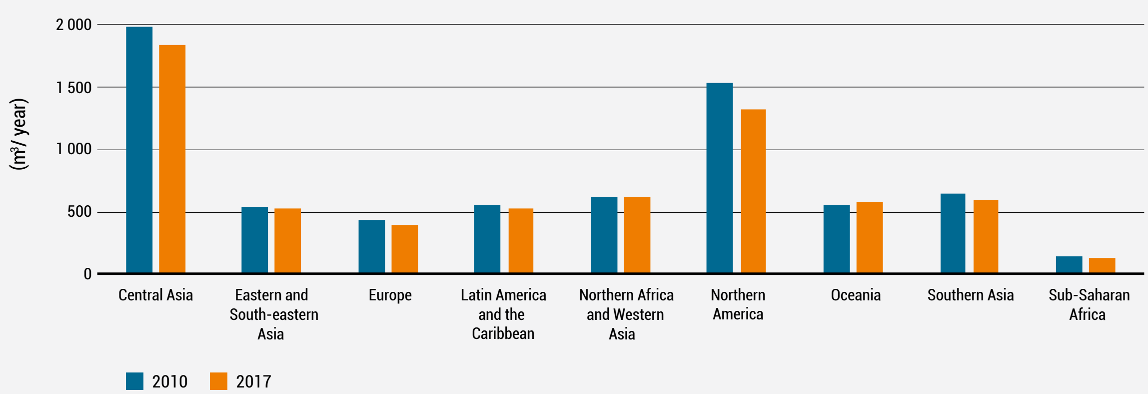
It is expected that the technical scope for water-use efficiency to be improved locally and taken to scale will continue to improve in all economic sectors, but operational water accounting will be needed to validate any claimed efficiency gains. A review of various national initiatives suggests that the economic and political cost of improved technology and governance of water allocation need careful appraisal prior to any public investment. This includes water quality in particular when water efficiency measures may exacerbate concentration levels and attenuate dilution processes.

Systems of water use are multi-purpose and multi-functional so that the often-complex cascade of use, consumption and re-use inevitably leads to a set of environmental trade-offs that have to be appraised and negotiated. Slowing the growth of water withdrawals or making desired re-allocations of conserved water will need water policy instruments and management decisions to be place together with strong support for the adoption of 'joined-up' water technology.

1 Background

Using freshwater more efficiently is considered a national and global imperative when trends in population growth are set against the limited volume of freshwater circulation. Global water use statistics indicate that per-capita withdrawals of freshwater for all purposes have and only shown a slight decrease in the last decade (FAO, 2020 p. 6-9; Figure 1). The overall conclusion would be that water use has become more efficient over time as populations have increased and that this has occurred through the application of technology combined with a degree of institutional adaptation. The implication is that water use has been managed more 'efficiently' in the sense that higher levels of production of goods and services have been sustained with the same level of withdrawals. The result has been an increase in water productivity in relation to other factors of production. For this reason, there is a keen interest in making further gains in water-use efficiency in order to sustain desired social, economic and environmental benefits for growing populations. Hence, within the 2030 Agenda for Sustainable Development, the water target for SDG 6.4 assumes that gains in water-use efficiency will continue to provide social, economic and environmental benefits in the long term and is expressed both in terms of the level of economic output per cubic metre of water withdrawn - termed 'water-use efficiency' - and the degree of exploitation of the freshwater resource - water stress (Box 1). Therefore, a key question for this Brief would be, that irrespective of the level of stress placed on renewable water resources, can further advances in the institutional and technical opportunities available to manage freshwater achieve the desired gains in water-use efficiency?

FIGURE 1: ESTIMATES OF PER CAPITA FRESHWATER WITHDRAWALS BY REGION



NOTES: Total water withdrawal refers to the annual quantity of water withdrawn for agricultural, industrial and municipal purposes. Population data refer to the World Population

Prospects: The 2019 Revision from UN DESA. Oceania includes Australia and New Zealand.

Source: FAO, 2020a.

BOX 1: SDG GOAL, TARGET AND INDICATORS

Goal 6. Ensure availability and sustainable management of water and sanitation for all

Target 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"

Indicators

6.4.1 Change in water-use efficiency over time (US dollars/m^3)
6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (%))

Note: Following International Standard Industrial Classification of all Economic Activities (ISIC) Rev. 4 codes, sectors are considered as:
Agriculture (ISIC A, excluding forestry and fishing)

Mining and quarrying, manufacturing, electricity, gas, steam and air conditioning supply, and constructions – MIMEC (ISIC B, C, D and F) All the service sectors (ISIC E and G to T)
Water-use efficiency (WUE) is calculated as the sum of these three sectors, weighted according to the proportion of water used (freshwater withdrawn) by each sector over the total uses, following the formula:

$$WUE = Awe \times PA + Mwe \times PM + Swe \times PS$$

Where:
WUE – Water-use efficiency [USD/m3]
Awe – irrigated agriculture water-use efficiency [USD/m3]
Mwe – MIMEC water-use efficiency [USD/m3]
Swe – Services water-use efficiency [USD/m3]
PA – Proportion of water used by the agricultural sector over the total use
PM – Proportion of water used by the MIMEC sector over the total use
PS – Proportion of water used by the service sector over the total use

2 Introduction – scope of brief[1]

Definitions and perceptions of 'efficiency' and 'efficient use' in relation to water withdrawn for human use are diverse. 'Water-use efficiency' might imply a strict ratio of water flow measured at one point to flow measured at another point in a hydraulic system. Or it may be used as a measure of productive output or benefit per cubic metre of water used or consumed (evaporated). The definition of units used in deriving such a ratio and the context or scale at which it is applied would therefore seem important to establish at the outset.

The SDG indicator 6.4.1 is predicated on comparisons of productivity – the aggregate economic output per unit of water withdrawn. The expectation from SDG target 6.4 is that increases in 'water-use efficiency' will improve freshwater availability for all users and maintain desired level of environmental flows. It is assumed that this will contribute to the achievement of related SDG targets in water access, water quality, environmental functions and transboundary cooperation and thus contribute to the broader SDG agenda. This requires that improvements that reduce water needed to produce a set of goods and services frees up water that can be reallocated among other users. This in order to facilitate improved access for unserved populations and keep aquatic ecosystem in play. If policies are put in place to ensure such reallocation, four specific outcomes that support the SDG objectives are envisaged:

- reduction in human suffering attributed to scarcity of water or water services;
- reduced or stable withdrawals of water from the natural and modified circulation of surface and groundwater;
- sustained production of freshwater water for supply; and
- reconciliation of competition for scarce water resources across economic sectors and meet environmental flow requirements for aquatic ecosystems.

To analyse the link between water use and SDG target 6.4, a clear understanding how water-use efficiency gains can contribute to the achievement of the SDG target is required. The cost of making such efficiency gains compared to the costs of developing new supply or the costs of failing to improve efficiency also needs appraisal (FAO, 2016a p.39.). To do this a review of water-use efficiency definitions will be made with respect to specific water-use systems in municipal, industrial and agricultural sectors broadly in line with the ISIC sector clusters used for the indicator (Box 1). However, it should be pointed out that the ISIC categorization for agriculture does not include "forestry and fishing" for which freshwater use can be significant.

Evidence-based policy responses would require that the technical and socio-economic performance of water-use efficiency measures are made comparable. In addition, the benefits and the beneficiaries of such

[1] *"The purpose of the Analytical Brief is to serve as a basis for discussions related to UN-Water's areas of focus through its Programmes, Thematic Priority Areas, and Task Forces. The Analytical Brief is used to identify potential activities for UN-Water and can be used as a tool for substantive discussions with various key stakeholders. The Analytical Brief is published in time for relevant major events and will support UN-Water to engage in discussions on emerging issues"* https://www.unwater.org/publication_categories/policy-and-analytical-briefs/

measures need to be clear from the outset. This Analytical Brief reviews the basis for such comparisons in respective operational (sector + infrastructure) and environmental settings. In relation to the water-use efficiency target set by SDG 6.4, this Brief will cover:

- definitions and measures of water-use efficiency relevant to natural hydrological systems and the main sector infrastructure; human-nature interactions and environmental impacts, including the relationship with productivity;
- where and to whom water-use efficiency matters including assessment of hydro-environmental outcomes from human-nature interactions (quantity and quality);
- a review of current (baseline) policy initiatives addressing water-use efficiency and dependencies in related policy areas e.g. climate mitigation, energy, (co-benefits and trade-offs); and
- a look at the prospects for water-use efficiency measures in changing climatic and socio-economic settings.

The Brief is necessarily restricted to water-use efficiency measures that directly impact the physical management of water withdrawals and associated environmental impacts. A detailed analysis of 'soft' policy responses to water scarcity including the use of resource pricing, withdrawal caps and related economic and financial measures to manage demand is beyond the scope of the Brief and is covered in more detail in the UN-Water World Water Development Report for 2021 (United Nations, 2021).

The purpose of this Brief is to provide an analytical basis for water-related policy interventions to implement the SDG target increases in water-use efficiency. Given changing socio-economic and climatic conditions and the level of uncertainty over future trends in freshwater scarcity, water efficiency gains will necessarily involve economic and environmental trade-offs, and there is particular concern for those who are particularly vulnerable and exposed to physical and economic risk as a result. This analysis of the current practice and impact of water-use efficiency measures will take a necessarily broad view across regions and sectors and is illustrated by relevant examples.

3 Definition and measures of water-use efficiency – linking hydrology to socio-economic benefits/costs

3.1 The SDG Indicator

This Brief has been asked to consider the implications of and prospects for 'water-use efficiency' (UN-Water, 2018) as it relates to the SDG target for water. The SDG 6.4.1 indicator for water-use efficiency[2] is a national macro-economic estimate of gross value added divided by gross freshwater withdrawals (termed 'use' but defined as 'freshwater withdrawals') for the three main economic sectors identified by ISIC – agriculture, mining + industry (including energy production) and services, as determined from national statistics. The indicator aggregates the value of economic output attributed to each sector cluster and divided by freshwater withdrawals attributed to the clusters. In this sense, the indicator can be taken as a measure of economic output per quantum of water withdrawn from the environment. As such, it permits national comparison of the intensity of water use in achieving a certain constant (deflated) monetary value of total output. It is stated that the SDG indicator 6.4.1 assesses the dependency of economic growth on water withdrawals. It tracks the rate at which water withdrawals change in relation to gross added value of the economy and claims to indicate progressive *"de-coupling of economic growth from water use"* (FAO, 2019 p. 24; FAO and UN Water, 2021)

However, the indicator has limitations. It is subject to errors inherent in statistical estimates of water withdrawals and related economic data. Indeed, the aggregation of sectoral statistics may obscure important partitions of water use. For instance, withdrawals estimated for agriculture aggregate irrigated agriculture, livestock watering and aquaculture. However, the frequency and reliability of such water withdrawal estimates are variable and may only be compiled at national level once every 5 or 10 years. By using withdrawal estimates (and not consumptive water uses) for each sector, the indicator risks double counting the withdrawals that occur downstream of another use, effectively inflating the water variable in the denominator. For national level comparisons, this use of gross withdrawals rather than net withdrawals complicates inter-country comparison where levels of re-use can be markedly different. As with related water stress indicator, it is argued that using net withdrawals would lend more precision in evaluating overall (basin-wide) water-use efficiency (Hellgers and van Halsema, 2021;). Further, the gross value added (in effect, gross domestic product or GDP) is skewed to toward services and industry where monetary values are high and water use low in relation to agriculture. The agriculture sector by contrast 'suffers' in the weighting scheme since it is locked into high inputs of solar radiation and evaporation by virtue of plant metabolism (Fereres *et al.* 2017) and consequently high withdrawals and low commodity values. It is also a sector where many poor smallholders lack the financial capacity to invest in water efficient technologies. For these reasons, it can be argued that the indicator does not capture all the multiple functions and non-market values of water use (human health, environmental values) that otherwise reflect the distribution or equity of the socio-economic benefits derived from water use. In addition, at river basin or aquifer level where actual water-use efficiency will count, particularly under conditions of physical water scarcity, the SDG indicator cannot provide any measure of water system performance.

As such the SDG 6.4.1 indicator it is not a precise measure or comparator of water productivity, i.e., the relative intensity of water input to produce a certain good or service – or the marginal net value of production per unit of water **consumed**. In addition, it should also be distinguished from the notion of 'economic efficiency' which is concerned with the allocation of resources across an economy to yield maximum net benefit to the economy as a whole – and is a criterion not a ratio (Wichelns, 1999). There are two considerations here. First, it is the relative volume of freshwater withdrawals and the quantity and quality of return flows in any economy that are important to consider when looking for efficiency gains, particularly when water is scarce. Second, it is the relative per capita benefit that a cubic metre of freshwater can generate that is relevant for economic analysis, which is typically measured as units of economic activity (USD per cubic meter or production per cubic metre) or population served (cubic metres per capita).

As will be outlined below, the term 'water-use efficiency' is subject to wide interpretation depending on discipline, sectoral outlook or the point of measurement. Since the concern of the SDG goal is the 'wasteful' use of water use in specific sectors or a specific water using practice, the interpretation of its indicators needs to be informed by attention to the definitions of water use and the method of measurement (Gleick *et al*. 2011; Perry, 2011).

3.2 The Indicator Challenge

The temporal and spatial scale of the challenge for the SDG 6.4 target is significant. The current categorization and general allocation of global freshwater resources sets the order of scale for this analysis and also points to linkages with other SDG targets. Table 1 lists the evolution of global freshwater withdrawals by sector since 1900 in relation to annually renewable supply of freshwater estimated at a 2010 baseline and a more detailed regional breakdown of the regional withdrawals is included as Annex 1. To set these withdrawals in their hydrological context, Box 2 gives schematic account of global water balance on data compiled for use estimates for the year 2004 (Hoogeveen *et al*. 2015) against which the scale of withdrawals can be compared. This points to where there should be greatest scope (in overall volumes) for policy interventions to make a difference. To give an idea of the orders of magnitude at global level, the incremental evaporation attributed to irrigated agriculture (its consumptive use) has been estimated at 1,268 km^3/yr (Hoogeveen *et al*., 2015) and the incremental evaporation attributed to artificial lakes and dams has been estimated at around 350 km^3/yr (FAO, 2015). The volume of consumptive use in agriculture is therefore large in relation to the non-consumptive uses associated with municipal and industrial supply and is estimated to account more than 90 percent of the consumptive use of global water withdrawals (FAO, 2012).

Projections for sectoral water use have been made through various modelling approaches. For instance, IIASAs Water Futures and Solutions programme gives global water demand figures of 3,447, 1,381 and 967 km^3/yr for agriculture, municipal and industrial sectors respectively in the year 2050 based on a "Middle of the Road" scenario (IIASA, 2016). Whether such projections conform to the slowing of observed withdrawals is debateable, but certainly the scale of the water-use efficiency challenge will not diminish.

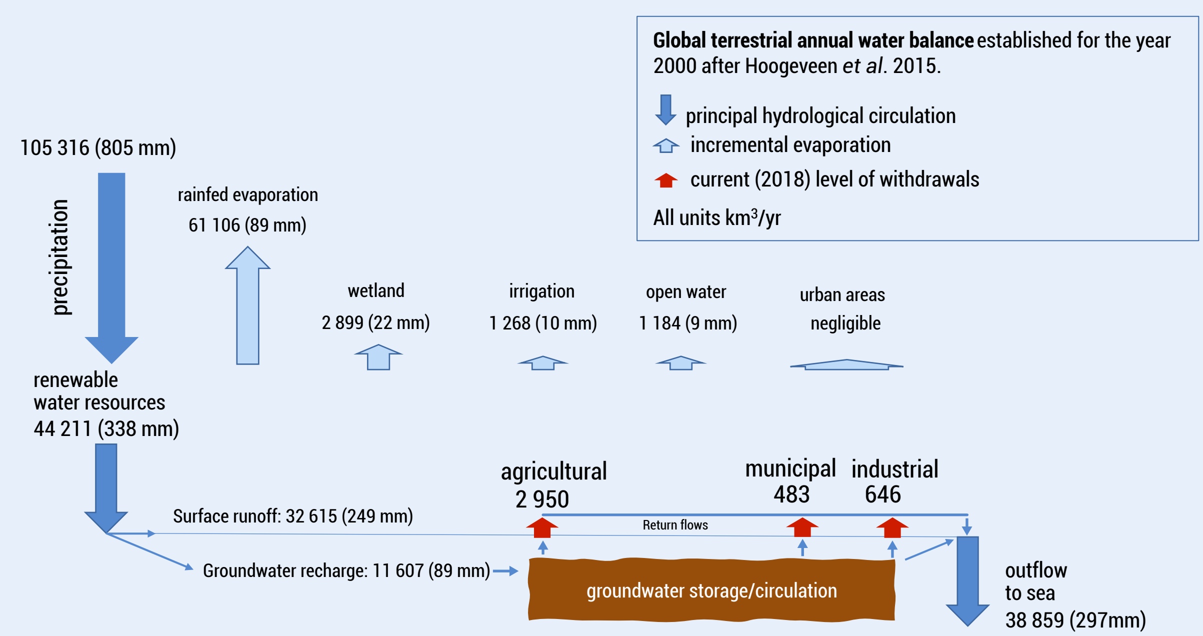
At national level, it is apparent that proportion of sector withdrawals and the potential scope for water-use efficiency gains is conditioned by population and income growth. Figure 2 illustrates the relative dependence upon sector withdrawals by income level and

TABLE 1. GLOBAL WATER WITHDRAWALS SINCE 1900 (KM³/YR)

	1900	*1960*	*1970*	*1980*	*1990*	*2000*	*2010*	*2018*
Agriculture	513	1481	1743	2112	2425	2605	2799	2950
Industries	43.7	339	547	713	735	776	731	646
Municipalities	21.5	118	160	219	305	384	470	483
Total	**578.2**	**1 938**	**2 450**	**3 044**	**3 465**	**3 765**	**4 000**	**409**
Incremental evaporation:								
from irrigation							1 268	-
over wetlands							2 899	-
over open water							1 184	-
Reservoir/dam evaporation	0.3	30.2	76.1	131	167	208	349	-

Source: FAO, 2020a. AQUASTAT. In: FAO [online]. [Cited 15 August 2020]. www.fao.org/nr/water/aquastat/data/query/index.html?lang=en and Hoogeveen *et al*. 2015.

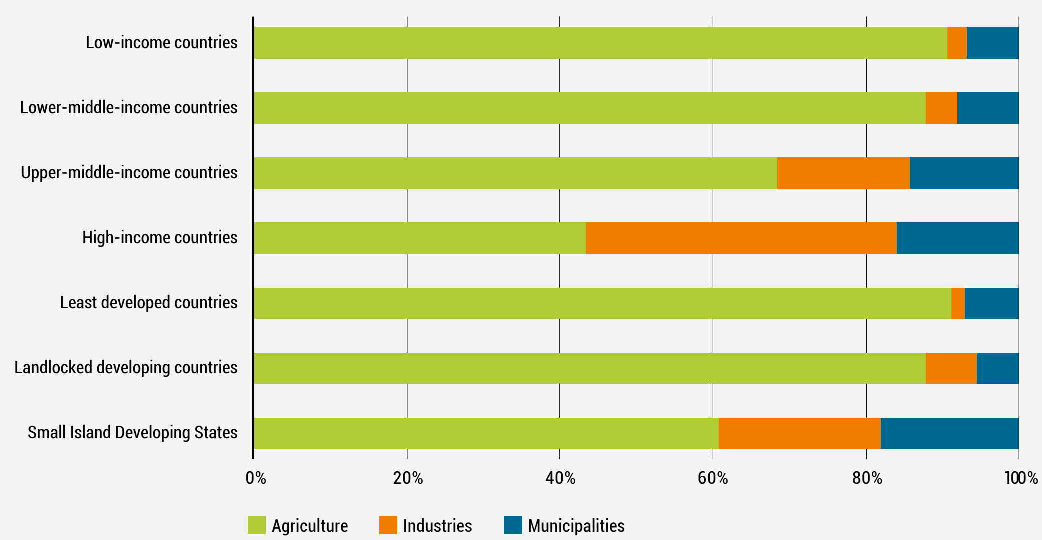
BOX 2: ESTIMATES OF GLOBAL WATER BALANCE AND GLOBAL WATER WITHDRAWALS BY SECTOR



charts the general transition from agrarian to industrial economies to indicate where sectoral interventions are likely to be effective.

For specific countries, water withdrawal data reflect inter-annual variation in water use and trends in per capita withdrawals. As an example, Box 3 presents the evolution of water use for Spain and Algeria, which indicate clear trends in per capita water withdrawals but otherwise no consistent trends in sector withdrawals that could be attributed to efficiency gains or declining annually renewable water resources over time. At country level, the processes by which real water-use efficiency gains can or are being made through improved water system performance can be obscured the use of aggregate statistics. The nearest national statistical index of physical water efficiency within a sector is the ratio of modelled estimates of irrigation water withdrawals and irrigation water requirements – the water requirement ratio (FAO-AQUASTAT, 2017) . These ratios have been based on one-time estimates of the crop water requirement derived from cropping calendars and harvested areas for each of 167 countries available in 2012. The results of this modelling exercise gave a global mean of 56 percent and a range over high-, middle- and low-income countries of 61 percent, 56 percent and 48 percent. This is comparable with the hydrological irrigation water requirement ratios calculated on the basis of hydrological basins which gave a global mean of 55 percent (Hoogeveen *et al*. 2015). Even in these exercises, the accuracy and consistency of national statistical data remains a challenge since in practice, data on key climate variables, harvested crop areas and annual hydrological balances will be fluctuating. The presumption that a consistent national level picture can be obtained annually is a condition that is rarely met and points to the need for support to national hydrology programmes in monitoring water uses and preparing water accounts.

FIGURE 2. SECTORAL WITHDRAWALS BY INCOME AND COUNTRY CLASSIFICATION, 2017



NOTE: Agricultural water withdrawal refers to the annual quantity of self-supplied water withdrawn for irrigation, livestock and aquaculture; industrial water withdrawal is the annual quantity of self-supplied water for industrial uses, such as cooling thermoelectric and nuclear power plants, but does not include hydropower; and municipal water is water withdrawn for the direct use of the population.

Source: FAO, 2020a.

3.3 General considerations in evaluating water-use efficiency

Water-use efficiency needs to be unravelled at operational levels if effective water and related sector policies are to be evaluated and adjusted to make a contribution to SDG 6. To make relevant comparisons of water-use efficiency within and across sectors, the measurement of any hydrological baseline needs to be conformable with the measurement of the productive use of water withdrawals. In addition, to assess the distributed socio-economic and environmental outcomes resulting from water-use efficiency initiatives, their potential impact needs to be evaluated in terms of both water quantity and quality. Finally, the prospects for future gains need to be set against anticipated rates of change in those socio-economic and environmental systems.

The latter point is important if resource managers are to gauge the performance of water-use efficiency measures. 'One-off' water accounts need to be repeated to provide operational accounts that reflect daily, monthly and annual water budgets and it is more insightful to use time series and trend analysis to pick out the effectiveness of such measures (FAO, 2016a).

In broad terms there is a distinction between water uses that result in evaporation, or consumptive uses (plant evapotranspiration, reservoir and cooling tower evaporation) and non-consumptive uses for which evaporation loss is considered marginal and which return withdrawn water back to the environment (hydropower generation, municipal water supply). Water stored in field crops and vegetables and assimilated in livestock and human metabolism

BOX 3. EVOLUTION OF SECTORAL USE IN SPAIN AND ALGERIA FROM AQUASTAT DATABASE.

Food and Agriculture Organization of the United Nations — AQUASTAT | Click for details on AQUASTAT symbols | English | CSV (Tables) | CSV (Flat) | « New search

Spain

	1988-1992		1993-1997		1998-2002		2003-2007		2008-2012		2013-2017		2018-2022
Agricultural water withdrawal *(10^9 m3/year)*	23.65I	(1992)	23.41X	(1997)	23.04X	(2002)	23.18X	(2007)	25.47X	(2012)	20.36I	(2017)	
Industrial water withdrawal *(km³/year or 10⁹m³/year)*	6.447I	(1992)	6.68X	(1997)	7.447X	(2002)	6.495X	(2007)	6.572X	(2012)	5.966I	(2017)	
Municipal water withdrawal *(km³/year or 10⁹m³/year)*	6.418I	(1992)	4.509X	(1997)	5.448X	(2002)	5.898X	(2007)	4.599X	(2012)	4.89I	(2017)	
Total water withdrawal *(10^9 m3/yr)*	36.52I	(1992)	34.6E	(1997)	35.94E	(2002)	35.57E	(2007)	36.64E	(2012)	31.22I	(2017)	
Irrigation water withdrawal *(10^9 m3/yr)*	23.6I	(1992)	23.09X	(1997)	22.93X	(2002)	21.2X	(2007)	23.37X	(2012)	18.64I	(2017)	
Irrigation water requirement *(km³/year or 10⁹m³/year)*									14.06I	(2012)	14.06I	(2017)	
Agricultural water withdrawal as % of total water withdrawal *(%)*	64.77E	(1992)	67.66E	(1997)	64.12E	(2002)	65.16E	(2007)	69.51E	(2012)	65.22I	(2017)	
Industrial water withdrawal as % of total water withdrawal *(%)*	17.65E	(1992)	19.31E	(1997)	20.72E	(2002)	18.26E	(2007)	17.94E	(2012)	19.11I	(2017)	
Municipal water withdrawal as % of total withdrawal *(%)*	17.58E	(1992)	13.03E	(1997)	15.16E	(2002)	16.58E	(2007)	12.55E	(2012)	15.67I	(2017)	
Total water withdrawal per capita *(m³/year per inhabitant)*	926.6E	(1992)	864.2E	(1997)	857.2E	(2002)	783E	(2007)	778.6E	(2012)	669.2E	(2017)	

Food and Agriculture Organization of the United Nations — AQUASTAT | Click for details on AQUASTAT symbols | English | CSV (Tables) | CSV (Flat) | « New search

Algeria

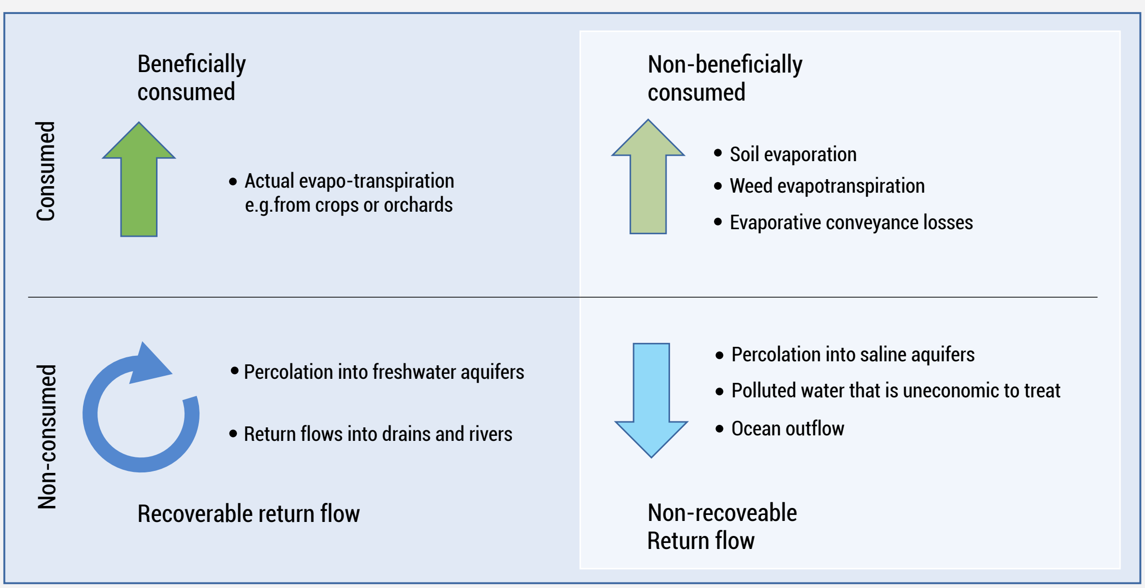
	1988-1992		1993-1997		1998-2002		2003-2007		2008-2012		2013-2017		2018-2022
Agricultural water withdrawal *(10^9 m3/year)*	2.846I	(1992)	3.21I	(1997)	3.637I	(2002)	4.314I	(2007)	4.99E	(2012)	6.671	(2017)	
Industrial water withdrawal *(km³/year or 10⁹m³/year)*	0.644I	(1992)	0.554I	(1997)	0.4858I	(2002)	0.4504I	(2007)	0.415E	(2012)	0.191	(2017)	
Municipal water withdrawal *(km³/year or 10⁹m³/year)*	1.24I	(1992)	1.541I	(1997)	1.938I	(2002)	2.479I	(2007)	3.02E	(2012)	3.6	(2017)	
Total water withdrawal *(10^9 m3/yr)*	4.73E	(1992)	5.305E	(1997)	6.061E	(2002)	7.243E	(2007)	8.425E	(2012)	10.46E	(2017)	
Irrigation water withdrawal *(10^9 m3/yr)*					3.502I	(2002)	3.502I	(2007)	3.502I	(2012)	3.502I	(2017)	
Irrigation water requirement *(km³/year or 10⁹m³/year)*					2.511I	(2002)	2.511I	(2007)	2.511I	(2012)	2.511I	(2017)	
Agricultural water withdrawal as % of total water withdrawal *(%)*	60.17E	(1992)	60.52E	(1997)	60.02E	(2002)	59.56E	(2007)	59.23E	(2012)	63.76E	(2017)	
Industrial water withdrawal as % of total water withdrawal *(%)*	13.62E	(1992)	10.44E	(1997)	8.016E	(2002)	6.219E	(2007)	4.926E	(2012)	1.826E	(2017)	
Municipal water withdrawal as % of total withdrawal *(%)*	26.22E	(1992)	29.04E	(1997)	31.97E	(2002)	34.22E	(2007)	35.85E	(2012)	34.41E	(2017)	
Total water withdrawal per capita *(m³/year per inhabitant)*	175E	(1992)	178.4E	(1997)	190.3E	(2002)	212E	(2007)	225.4E	(2012)	252.8E	(2017)	

is also a consumptive use. For agricultural use, there is then a further distinction between evaporation that is beneficially consumed and non-beneficially consumed plus a distinction between recoverable return flows and non-recoverable return flows as illustrated in Figure 3.

In practice, it is not possible to be so categoric and the distinctions may become blurred. For instance, water applied to soil or intercepted by vegetation may be important in cooling a crop or forest canopy. The residual or return flows (drainage and aquifer recharge resulting from irrigation, municipal wastewater streams, industrial cooling return flows etc.) will include varying amounts of pollutants and may or may not be 'recoverable' in economic terms. Certainly, at micro-economic level, the perceptions about the use of water and its characterization in space and time are highly varied so that notions about 'efficient use' are conditioned by individual and collective perspectives (Di Baldassarre *et al*. 2019) as much as the transient nature of rainfall and runoff (Beven, 2016).

There are three important considerations here. First, that it is impossible to attribute any one type of water use exclusively to consumptive or non-consumptive use. Second, the point at which withdrawals and consumption are measured and the areas and time over which evaporation and drainage are integrated need to be fully appreciated. The point at which water is applied for a specific use can be near or far from the point of withdrawal. Third, the scale at which such measurements of water use are taken or estimated have to be taken into account, particularly if there are error terms in the measurement or estimate, which can then accumulate at higher order scales. The conclusion here is that measures of consumption and measures of return flows and return flow quality are important for all sector uses when discussing water-use efficiency.

FIGURE 3. WATER USE CATEGORIES



Source: FAO Water scarcity programme. After Jägermeyr *et al,* 2015

3.4 Sector definitions of water-use efficiency

In strict sense, an assessment of water-use efficiency would involve measurement of water inputs and outputs across a bounded system to give a dimensionless ratio that allows comparison of the system performance with another performing exactly the same function. For a water engineering system (e.g. a wastewater treatment plant) this would be a measure of the evaporation losses or leaks that occur across the system (open channel evaporation losses, pressure relief valves or leakage from pipe joints). Clearly type of gains that can be sought in highly engineered systems, including water recycling, involve quite complex operational decisions and economic trade-offs, particularly with associated energy, capital, or material use (Liu *et al*. 2020) and may include the environmental impacts of residual water leaving the plant or site. This strict interpretation of efficiency is not used by the SDG 6.4 indicator, which opts instead for a generalised notion of economic output per cubic metre of water withdrawn across three economic sectors. The adoption of such a metric notwithstanding, the operational standards for measuring and accounting for water use will be examined for each of the three principal water using sectors – industry (including mining), municipal water supply and disposal, and agriculture.

As stated above, the concern of SDG 6 target is the level of human water withdrawals from the hydrological cycle, how they are allocated how they are used and how they are returned to the hydrological cycle. The SDG target recognizes that the act of use induces levels of evaporation over land that are above natural rates, the consumptive uses arising from, manufacturing processes, artificial storage and conveyance of water, crop growth and water spreading for irrigation. That this level of use is inducing stress on economies, their human populations and the aquatic environment is the particular concern of the SDG 6.4 target and its implicit assumption that water consumed or lost to a non-beneficial or unproductive purpose (the 'losses from the productive systems) should instead be avoided or conserved and directed toward a beneficial purpose.

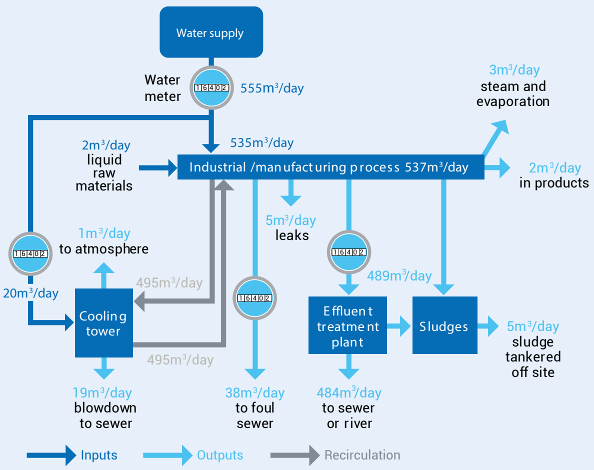
3.4.1 INDUSTRY

For general industrial uses, Box 5 illustrates the input and output elements involved in a sample industrial complex and the general categorization of water use in a typical industrial plant (WRAP, 2013). This illustrates the range of water inputs and outputs across part of a supply chain with the overall make up of water use in one manufacturing process from which an estimate of on-site water-use efficiency can be made and monitored over time to see if technological or operational changes reduce overall use and improve the water-use efficiency ratio – i.e., toward the limit of 1 on that specific industrial plant site. Indeed, bodies such as the Beverage Industry Environmental Roundtable has an established water efficiency benchmarking program for the leading global beverage companies and reports an aggregate water-use efficiency gain of 4 percent from 2013 to 2017 for 19 participating companies and 1 636 facilities (BIER, 2019).

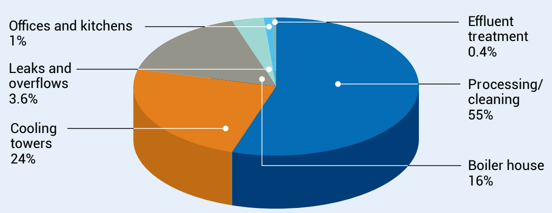
Similar industry association guidelines for the mining industry (ICCM, 2017) presented in Box 5 are clear about efficiency being expressed as the percentage of water recycled/recovered in the domain of the mine and the use of a productivity term (intensity of use) per tonne of material moved, ore mined or processed and/or the final product. However, these industry guidelines will not always bear comparison with all the water use categories set out in Figure 3 to the extent of including conveyance losses or classification of discharged water as recoverable or not.

BOX 4: INPUTS AND OUTPUTS IN A SAMPLE INDUSTRIAL SITE

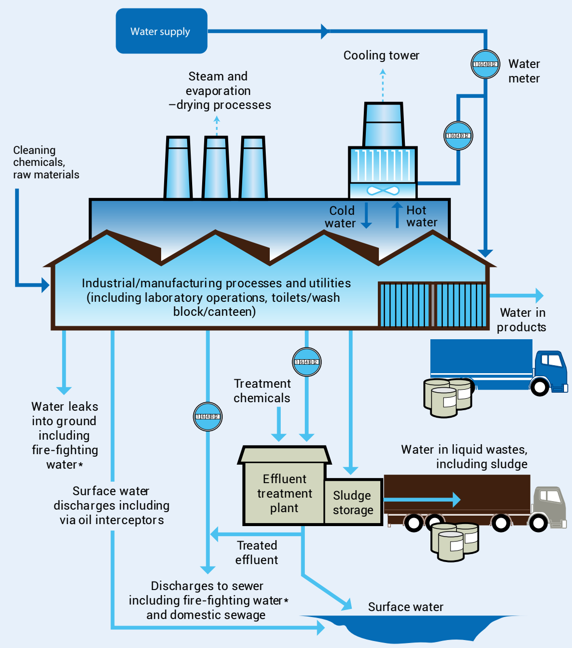
Water balance for an example industrial site



Water use in food manufacture



Water inputs and outputs for an example industrial site



Source WRAP, 2013.

BOX 5: EXAMPLE OF WATER ACCOUNTING STANDARD USED IN THE MINING INDUSTRY

Objective	Metric	Definition	Calculation approach	Rationale
Standardised metrics which, following company-wide compilation, form the basis for external corporate water reporting	Withdrawal	The volume of water (ML) received by the operational facility, by type (surface water, groundwater, sea water or third party water) and two categories of quality (high and low).	• Based on operational flowcharts, site water circuit diagrams and/or water balance data. • Calculated as MCA WAF Inputs (see Table 4). • For detailed guidance see WAF User Guide[6].	Key metrics in defining a site's water dependency and the potential for associated water risks (physical, reputational or regulatory) and opportunities.
	Discharge	The volume of water (ML) removed from the operational facility to the water environment or a third party, by receiving body (surface water, groundwater, seawater or third party) and two categories of quality (high and low).	• Based on operational flowcharts, site water circuit diagrams and/or water balance data. • As MCA WAF Outputs to Surface Water, Groundwater, Seawater and Third Party Supply only (see Table 4). • For detailed guidance see WAF User Guide.	
	Consumption	The volume of water (ML) used by the operational facility and not returned to the water environment or a third party, by two categories of quality (includes: evaporation (and transpiration); water incorporated into product and/or waste streams (entrainment); and other operational losses.	• Based on operational flowcharts, site water circuit diagrams and/or water balance data • As MCA WAF Outputs (Other) - see Table 4 • May be calculated by balance (see Figure 2), as for a given period: Withdrawal = ΔStorage + Discharge + Consumption • For typically dry or zero-discharge sites, the consumption volume is likely to be similar to the withdrawal volume, and may often be termed new water or make-up water.	A key metric in understanding a site's water dependency, use and associated risks. Also, provides insight into the opportunity to use of lower quality water to meet the site water demand and reduce the consumptive use of high quality water.
	Efficiency	The total volume of both untreated and treated water used in tasks (ML) which has already been worked by the site (ie previously used and recovered) as a percentage (%) of the total volume of all water used in tasks (ML).	• See Appendix B for further definitions and a worked example • Calculated from the WAF site system representation developed using site water circuits and flowcharts • As MCA WAF reuse efficiency + MCA WAF recycle efficiency • For detailed guidance see WAF User Guide	Important metric for understanding a site's water management practices and ability to enhance sustainability by reducing the withdrawal volume required to meet the site water demand. This metric is especially relevant in water stressed areas, with typically lower water availability and higher competition.
Internal use only	Intensity	The total volume of water consumed per tonne/unit of material moved,ore mined, ore processed and/or final product – as appropriate to the operational facility.	• Calculated using the total volume of water consumed and tonnes/units of material moved, ore mined, ore processed and/or final product.	This metric is being introduced to enable the industry to internally develop a meaningful intensity metric which, informs performance monitoring and benchmarking, and in the mid-term may be used for external water reporting and/or embodied water calculations.

Source: ICMM, 2017.

3.4.2 MUNICIPAL WATER SUPPLY AND WASTEWATER

For municipal water supply utilities where costs of bulk water production can be set against revenues derived from its sale, the percentage of unaccounted for water (principally leakage and theft) is taken as general measure of the network's water-use efficiency. Operational practice within the industry also uses absolute losses per connection per day as an indicator of supply network performance. The term 'non-revenue water' is also frequently employed (World Bank, 2016b) to include authorized use such as firefighting which can be accounted for but is not a source of revenue. These are economic metrics that tell managers and regulators about the potential for improving revenues and cost recovery.

Table 2 sets out the range of characteristics and indicators for non-revenue water. The global estimate of physical water losses at 32 km^3/yr each year, half of which occurs in developing countries (World Bank 2016a).

Here it is significant that water regulators accept that there is an economic level of leakage at which the value of the water to be saved by further leakage control equals the marginal cost of implementing the saving (OFWAT, 2021). Financial accounting may also take into account non-revenue water including authorised use, such as firefighting, which is not billed. It is important to be aware of which categories of use are included in any financial statement offered by supply utilities – whether public or private.

3.4.3 AGRICULTURAL USE

Agricultural systems in natural landscapes are much more difficult to evaluate in such neatly bounded engineering terms. Precipitation falls on land randomly and can evaporate, sublimate, infiltrate or runoff immediately. As soon as water is artificially channelled, stored and withdrawn to spread on adjacent land, the natural cascade of flow and associated kinetic and thermal energy is modified, exposing more surface area from which evaporation can occur. The range of infrastructure used for storage and conveyance is wide, from large dams and primary conveyance canals down to field level micro-structures for rainfall capture and flow diversion. However, in terms of agricultural production, crop data reported at national level may not distinguish between rainfed or irrigated production, let

TABLE 2: CHARACTERISTICS OF COMPONENTS OF NON-REVENUE WATER

Component	Examples	Indicators	Value of Reduced NRW: When short-term demand is met	Value of Reduced NRW: When saved water can be sold
Unbilled authorized consumption	Unbilled government, firefighting; pipeline flushing; and some public uses, such as mosques	• Liters/connection/day • Unbilled authorized consumption/ billed consumption	Retail price of water (and sewer)	Retail price of water (and sewer)
Apparent (Commercial) losses	Meter under-registration; unauthorized water use; billing errors	• Liters/connection/day • Commercial loss/billed consumption	Retail price of water (and sewer)	Retail price of water (and sewer)
Real (Physical) losses	Leakage from distribution mains and service connections, tank overflows, etc.	• Liters/connection/day • m^3/day or m^3/km/day • Value of physical losses/ operating cost	Variable operating cost of water production	Retail price of water (and sewer)

Source: World Bank, 2016b.

alone the source of irrigation water. For these reasons, attributing agricultural production to specific quantities of water will always need careful untangling in national water accounts.

In practice, determining precisely which measured (or estimated) water input term to use, and at what point and time of input, is not straightforward (Perry *et al*. 2009; Lankford, 2012). Scale dependency is an inconvenient truth and many assumptions about the overall efficiency of irrigation systems may have been derived from comparisons of 'field application efficiency' where gravity, sprinkler and micro-irrigation technologies can exhibit indicative efficiencies of 60 percent, 75 percent and 90 percent respectively (FAO, 2002). But as the US Government Accountability Office (2019) note, while there is evidence for water application efficiencies being achieved for certain technology shifts and crop types, the argument that these application efficiency gains translate directly into water conservation cannot be made.

For crop scientists, the term 'water-use efficiency' has a very specific meaning. It is the amount of carbon assimilated as biomass that is produced per unit of water used by a specific plant or crop (Hatfield and Dold, 2019). Again, in strict terms, this a measure of water productivity (carbon assimilated) at the level of the transpiring leaf and an important indicator of crop performance that can be used to select plant varieties that have the most water efficient genotypes. However, at field or canopy level in the micro-climate surrounding the transpiring leaf, the field level definition of water-use efficiency can also include the combined evaporation from the soil surface and the transpiration from growing leaf surfaces plus the periodic evaporation of intercepted rainfall. Rainfed agriculture is naturally 'efficient' in the sense that it imports no water and evaporates or 'consumes' at a rate comparable with some types of natural vegetation. Although not in all cases. Since the ecosystem modification through selection of crop type, planting schedule, rooting depth and treatment of soil to lengthen the availability of moisture in the root zone can enhance evapotranspiration significantly (Morison *et al*. 2008).

The crop-based approach to water consumption generates another common form of technical water efficiency calculation – irrigation efficiency[2] as the ratio of crop water requirement to the volume of water diverted into a specific 'domain' or field/irrigation scheme boundary (FAO, 2016a p. 85-6). This requirement can include water applied for leaching and weed suppression. However, use of the term 'efficiency' implies that that water is being 'wasted' when the efficiency is low. This is not necessarily the case. The recoverable fraction of the non-consumed water can be used further down-stream in the irrigation scheme, it can flow back to the river or it can contribute to the recharge of aquifers. It is for this reason that FAO has used the term "water requirement ratio (FAO-AQUASTAT, 2017)" when referring to the ratio between irrigation water requirement and the amount of water withdrawn for irrigation at national level.

As already illustrated in Figure 3, a further sub-division of evaporative loss is also applied in the case of agriculture. Beneficial consumption is defined as evaporation that results in carbon assimilation (transpiration) and evaporation that results from water applied to for weed suppression in rice paddy, leaching of salts and land preparation. Non-beneficial

[2] The ratio or percentage of the irrigation water requirements of crops on an irrigated farm, field or project to the water diverted from the source of supply. Also called 'Overall irrigation efficiency', or 'project efficiency' (Ep), comprises conveyance efficiency (Ec), field canal efficiency (Eb), and field application efficiency (Ea). (AQUASTAT Glossary 2019)

consumption is simply defined as unproductive evaporation (evaporation from conveyance canals, spray/sprinkler aspersion losses, weed transpiration and evaporation from bare soil). Water conservation management in rainfed and irrigated agriculture aims at reducing this non-beneficial evaporation and routing more of the applied water (irrigation plus rainfall) to beneficial consumption (Batchelor *et al.* 2014). At scale, the combination of water efficient genotypes and water conservation management can bring about a water use-efficiency gain for a particular farmer or scheme operator. The residual water that drains from land can also be subdivided into recoverable and non-recoverable fractions and can result in changes in basin storage whether aquifers or surface channels, as illustrated in Box 6.

In practice, the boundaries between these categories of agricultural water use are blurred or can be subject to interpretation (Burt et. al. 1997) and the range of efficiency definitions and water variables that are employed is potentially confusing (Perry, 2011, Van Halsema & Vincent, 2012). As noted by Kay (2020) measures of irrigation water-use efficiency may vary over the inclusion of;

- scale of measure (field, scheme, river basin)
- water inputs (applied water, rainfall, soil moisture),
- consumptive processes (transpiration from leaf surfaces, evaporation from bare soil, evaporation from intercepted rainfall) and
- drainage terms (return flows, deep percolation to underlying aquifers).

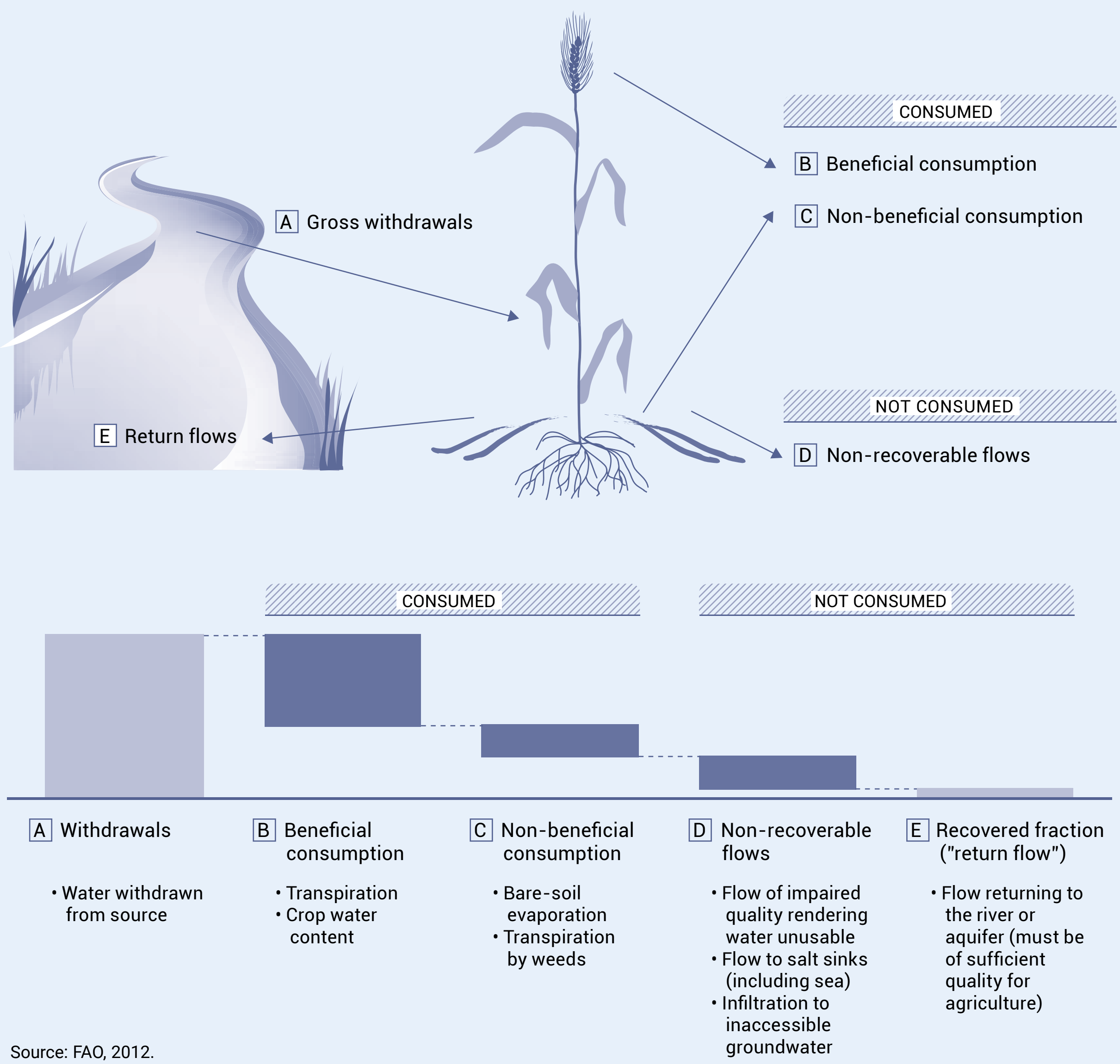
The test for many of these definitions depends upon whether the processes can be measured (application, consumption, drainage) and integrated adequately to present a definitive water budget for an irrigated crop to allow comparison with the same crop grown with different technologies (Bos and Nugteren, 1990). However, as observed by Kay (2020, p. 70)

> **"...the agronomic demand for water remains the same irrespective of the irrigation method. The water required to grow a crop is largely determined by the crop and the evaporating conditions, not by the irrigation method."**

Therefore, in the case of agriculture, any consideration of water-use efficiency or water productivity calculations needs to look carefully at the nature and composition of the denominator – where it is measured (at the point of withdrawal or the point of application), what elements of the consumptive use are included (evaporation terms and assimilation in biomass)and whether return flows are included in the account.

Finally, the act of spreading diverted or pumped groundwater directly on to land generates a set of environmental externalities in the form of reduced in-stream flow and aquifer recharge/ storage that resonate at river basin/aquifer level. These can be viewed as positive if the return flows generate new points of recharge or extend wetlands and effectively re-cycle water for downstream/down gradient users (Seckler, 1996). Equally, return flows can generate negative externalities in the form of nutrient rich, pesticide-laden return flows and the creation of saline sinks. The degree to which these water quality externalities determine the overall 'efficiency' of water use across a river basin can be significant. Heavily re-circulated water used for irrigation such as the Nile and Indus basins when combined with urban waste water does result in deltas whose agricultural productivity is compromised by salinity and synthetic pollutants (Molle *et al*, 2018: Solangi *et al.* 2019).

BOX 6 : SCHEMATIC ILLUSTRATION OF AGRICULTURAL WATER USE TERMS AND FRACTIONS



Source: FAO, 2012.

3.5 Domains and dimensions

The examples in water treatment systems, crop science and irrigation are an illustration of why it is important to appreciate the dimensions or units used and the boundary conditions that apply to specific 'domains' if they are to be made comparable. The categorization of uses in agriculture also makes it hard to pinpoint precisely where it is possible to make efficiency gains since the boundary between beneficial and non-beneficial uses is not always clear or measurable. For example, latent heat exchanges in and around the plant canopy can be viewed as non-beneficial if considered as evaporation from bare soil or beneficial if contributing to cooling of a growing crop. The ambiguity over definitions of consumption and the proportion of return flows has led to the consideration of water use fractions to partition the cascade of water into categories of use and consumption (FAO, 2016a p76-77) as illustrated in Box 6. Practice in applying water accounting methods has found that it is important to highlight water flows and evaporative fluxes and engage those making decisions in fractional analysis (FAO, 2016a).

If it is clear that care has to be taken in defining the output, (whether it is water of a certain quality, biomass, grain yield or monetary value) in the numerator, then measurement of the denominator is equally important.

3.6 The link with water productivity

The more general ("across all sectors") discussion on water-use efficiency is generally centred around the relative productivity derived from the input of water, whether in biomass, generated energy, manufactured output or human welfare. This reflects the general aspiration for SDG target 6.4, which is to make efficiency savings in particular sectors and water management operations. Comparisons of the performance of production systems in relation to water inputs (kg/dollar or levels of service delivered per cubic metre of water used) can reflect the intensity of water use in a production process or the delivery of a water service. Water productivity is therefore held to be a useful and universally applicable metric allowing comparison of the relative performance of an industrial process, water treatment plant or specific crop. However, care has to be taken when considering the sectors that withdraw large amounts of water (thermal energy and agriculture production) but whose actual level of consumptive use is very different. Thermal energy production consumes comparatively little in terms of evaporative cooling at the point of generation and returns the bulk of withdrawals directly to stream flow. Irrigated agriculture by contrast can consume significant volumes in evaporative loss from storage and conveyance as well as the volumes from beneficial evaporation at the point of production. For this reason, productivity comparisons in agriculture take care to use total water evaporated in the denominator, not 'gross water withdrawals' (van Halsema & Vincent, 2012). As was pointed out in the introduction, this exposes a limit in the SDG indicator since it uses gross water withdrawals at the point of abstraction, not the point of application/use (the root zone/canopy) where the actual production is measured and expressed as land productivity (typically crop yield per hectare).

The analytical challenge here is that production in relation to water inputs can have several factors of production – not just water. Further, the generated monetary value of the product is dependent upon local market price volatility and/or global commodity exchange price levels. These considerations of total factor productivity notwithstanding, water productivity can still help make point-to-point comparisons where all other factors of production are equal (i.e. within a scheme or project). However, at national level, the SDG indicator aggregation across sectors can be skewed by very contrasting sectoral measures of water productivity and incomes.

Recent overviews of agricultural water productivity have been given by IWMI (2017) and subsequently the World Bank (World Bank, 2018a) to highlight the linkage to water scarcity and the limitations of single-factor productivity metrics. Economic perspectives of water-use efficiency in agriculture are therefore tending to steer away from considering single factor productivity comparisons and reflect agricultural performance in terms of all factors of production, or total factor productivity. Here the relative importance of all inputs is taken into account including the managerial behaviour of water users who may not always seek to maximise production but opt for lower levels of production risk and lower than optimum inputs.

3.7 Methods of measurement of water use

The standards of measurement used in monitoring inflows, outflows, changes in system storage and evaporative losses allow comparison of water-use efficiency. In most industrial processes, the application of measurement standards and the calibration of flow meters are governed by national or international norms. For flows across river basins and through aquifers, guidelines for standard measurement are issued by national standards authorities and the World Meteorological Organization. Pre-calibrated measurement structures such as Parshall flumes are commercially available and so too are more sophisticated flow meters and data loggers. However, well-organised measurement of rainfall, soil moisture and surface flows at spatial and temporal resolutions to determine strict water use efficiencies across landscapes are rare. Much of the debate over the applicability of water-use efficiency and water productivity measures have to do with elements of the hydrological cycle that are not directly measurable or cannot be neatly labelled. While calibrated river gauging stations can give good integrated measures of basin flow, the processes upon which discussions over agricultural efficiency hinge, evaporation and groundwater recharge, are rarely directly measured or easily integrated in time and space. Over the past decade progress has been made with relatively high-resolution remote sensing products (~10 km^2 at the equator) to track and monitor changes in the water environment. Where adequate calibration of time series in image signatures can be derived, these products are starting to refine terms in basin level water balances (see Box 7).

In practice, the patterns of water use, consumption through evaporation, changes in aquifer storage and drainage in most hydrological units are complex. So too are the range of operational decisions made by water users. Discrete categories of use and 'consumption' are confounded by the inability to measure and monitor hydrological variables with sufficient precision to make aggregate accounts of the sort envisaged in Indicator 6.4.1 comparable from year to year. For this reason, the Brief looks at water-use efficiency in terms of the operational scope for water-use efficiency gains that can be expected to make some impact on the indicator.

In some cases, evaluation of efficiency measures can be made against natural environmental or pre-development hydrological regimes that in effect form an efficiency baseline. Naturalised flows may be sufficiently calculated to measure the departure from that baseline in terms of increases in consumption through incremental evapotranspiration resulting from irrigation and drainage and open water evaporation from storage structures and constructed channels. It may also be possible to track incremental recharge to underlying aquifers where a pre-development baseline can be established.

Linking water variables to economic performance still requires the collection of statistical data. At global level, national statistical accounts are reported by FAO AQUASTAT, which attempts to standardise national reporting on water use. Because actual withdrawals of irrigation water are only periodically estimated in agricultural census data, water requirements for crop production is also modelled in order to fill data gaps) in order to estimate total crop water consumption at national level (FAO-AQUASTAT, 2017).

National and river basin physical water accounting methods have come into play where water scarcity is recognized as a national policy issue (FAO, 2012). It is now possible to see national systems of water use accounting for various water using sectors (Godfrey and Chalmers, 2012). But there are several caveats here. At national level, water withdrawal statistics will be estimated with varying margins of error in most economic sectors. Equally, consumptive losses between the point of withdrawal and point of application can be measured only when water control in open channels is good, but even this will be done with varying degrees of accuracy.

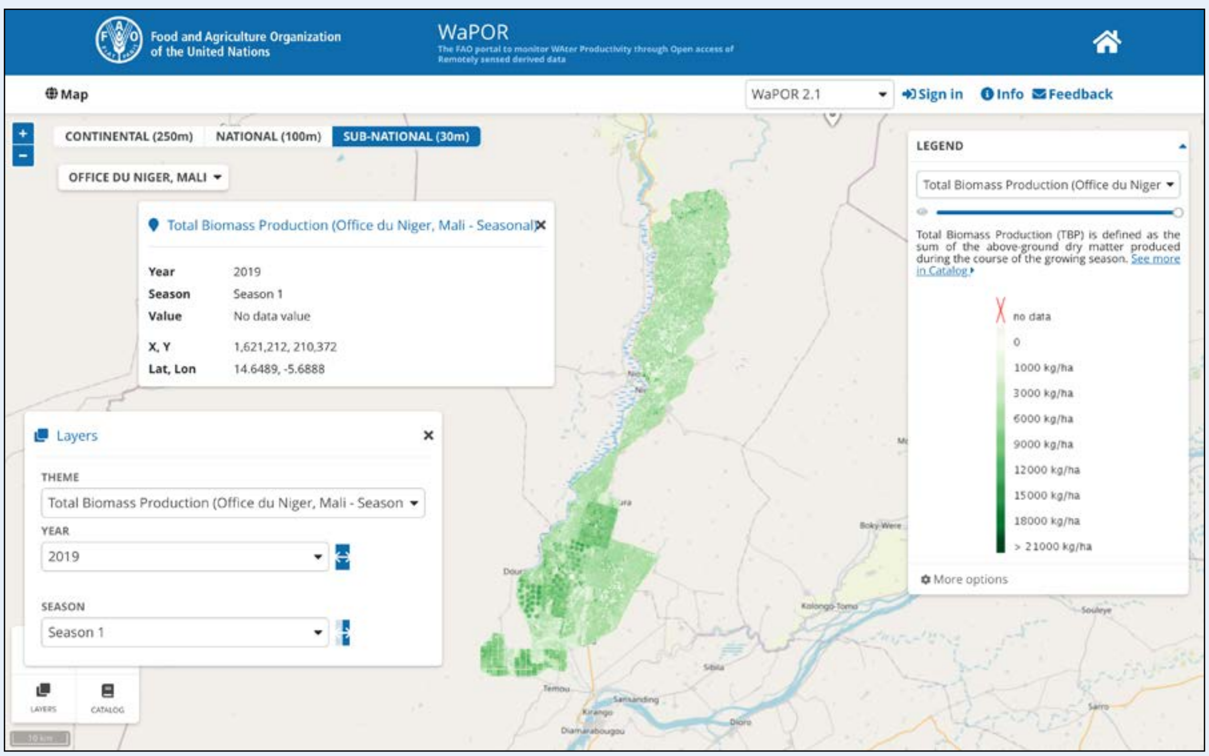
Examples of the main methods are given below:

- The linkage between measures of physical use and economic performance have now been developed in the UN System of Environmental-Economic Accounting for Water (UN SEEAW) (https://seea.un.org/content/seea-water), which gives the basis for the SDG 6.4.1 indicator to the extent that it links water use to economic activity and environmental processes. It is an aggregate account - reliant on statistical reporting at national level and in this sense is not linked to hydrological processes.
- Another accounting approach linked to economic production is given by detailed tracking of water used in specific production chains – the water footprint (https://waterfootprint.org/en/) offered as guide to producers and consumers of the level of water use involved in the production, processing and delivery of manufactured items (UNEP, 2011). The inclusion of corporate reporting of water use and productivity through initiatives such as the Carbon Disclosure Project (CDP, 2020) can also be recognized as sources of information. However, for many reasons the use of such value chain approaches do not aid comparison of water-use efficiency in food production (Fereres *et al*. 2017). For instance, cereal production, whether rain-fed or irrigated, is predicated on very high throughput of water and solar energy and comparing the throughput with water or energy use in manufactured goods does not reveal a comparative advantage in water use.
- The statistical or nationally aggregated approaches can be contrasted with the operational systems of water accounting and auditing practiced by such countries as Australia where annual accounts of water use at river basin level have to be reported under the General Purpose Water Accounting standards (as required under Australia's National Water Initiative (http://www.bom.gov.au/water/nwa/2019/). This system identifies flows and storage 'assets' and also liabilities under water use rights and is reported in specific basin 'reaches' to allow year to year comparison at user scale.
- The more hydrological oriented approach of Water Accounting Plus (www.wateraccounting.org) represents an outgrowth of the fractional approach illustrated in Box 6 in which river basin water balances can be linked to remote sensing products to provide annual or time series data sets to identify changes in patterns of consumptive (evaporation) uses.

Of these methods, only GPWA and WA+ allow identification of water balances within hydrological units. As part of the WA+ compilation, it is now possible to measure primary above ground productivity of all vegetative growth with remote sensing techniques that measure latent heat flux caused by evaporation at the surface and vegetative state (Simons *et al*. 2020). These measures allow basin water balances to be refined with respect to evaporative 'losses' from cultivated and natural vegetation on a regular (10 day) basis and thereby improve estimates of actual water use as cultivated and natural vegetation grows and dies back (Box 7). However, even where satellite-based monitoring of irrigation water use is possible, the accumulation of error terms can be significant to the point where it does not provide a reliable method of operational accounting without careful calibration (Foster *et al*. 2020).

One of the notable omissions of the main accounting systems (SEEAW, WA+ systems) is changes in aquifer storage. This is understandable. The only direct local proxy for groundwater storage is piezometer readings which have to be processed (Rau *et al*, 2020), interpreted and modelled before any aquifer 'account' can be prepared – assuming all boundary conditions are established. For instance, the UK Environment Agency now has its National Groundwater Modelling System (Deltares, 2013) partially implemented in order to regulate groundwater withdrawals. But very few countries have equivalent national groundwater modelling

BOX 7: WAPOR SAMPLE OFFICE DU NIGER, MALI



Source: FAO. http://www.fao.org/in-action/remote-sensing-for-water-productivity/en/

systems with which to support water regulation. Changes in groundwater quality as a result of withdrawal and recharge cycles add another order of complexity, which can be locally significant, but very difficult to 'account' for.

3.8 The role of modelling

Making sense of the benefits and costs associated with the circulation of water for human use to identify points at which water-use policy measures can be applied is not straightforward. As economies become more interwoven, use has been made of hydro-economic models to project demand for water services and deduce economic outcomes. Such models can range from sub-national levels to global (FAO, 2016a, World Bank, 2018a; Kahil *et al*. 2018) and can be used to plan multi-functional, multi-use systems and look for technical and economic efficiencies (e.g. Matrosov *et al*. 2015).

Modelling at the scale of national economy through general economic models (Computable General Equilibrium models – or CGE models) to reflect the aggregation in the SDG indicator 6.4.1 is also challenging. As noted in the World Bank review of agricultural water productivity (World Bank, 2018a), the specific water linkages or dependencies can be lost and the data available at national level is not necessarily conformable with ratios of input and output that are being examined for the purpose of water-use efficiency analysis.

A more specific use of modelling to update, quality check and fill data gaps in national accounts of irrigation water use has also been made (FAO, 2017). Where irrigation water withdrawals are not known these have be modelled using irrigated cropping calendars to determine irrigation water requirements.

The changing conditions of water scarcity under climate change present another layer of complexity. Attempts to model rainfed and irrigation transitions (soil moisture conservation and surface to sprinkler to drip technologies) have been made to indicate the levels of agricultural water productivity theoretically achievable under climate forcing and the scope for maintaining current levels of production with reduced agricultural withdrawals. (Järgermeyr *et al*, 2015:2016) The recent IPCC special publication on land points to feedback loops in energy and atmospheric moisture resulting from land use changes but does not report any impacts of climate change on patterns of irrigated production through global ensemble simulations (IPCC, 2019).

4 Application of water-use efficiency policies in practice

Where has water scarcity driven water-use efficiency measures to be adopted as policy measures? Water scarce economies have declared and funded programmes in water-use efficiency in order to reduce pressure on available water resources and maintain environmental flows. Notable OECD examples include Australia, while Mediterranean countries such as Morocco, Tunisia and Israel have included initiatives under the Plan Bleu reporting (Plan Bleu, 2019) and European countries have recognized water-use efficiency as part of the EU Water Framework Directive (EEA, 2012). Improvements in water-use efficiency in both urban and agricultural sectors in California and much of the arid western United States have been a major water policy objective in the 21st century (Gleick *et al.* 2014). The application of water-use efficiency measures can also be recognized at national level as part of drought management or water resource/eco-system protection measures arising from national policy or through alliances of environmental and research interests (The UK Droughts & Water Scarcity Research Programme, 2021). In general, these tend to be national programmes of water demand management that aim to apply a mix of communication material with regulatory incentives (public subsidies for adoption of new technology adoption) and penalties for exceeding quotas or caps on withdrawals or levels of pollution. A detailed analysis of demand management policy application is beyond the scope of this Brief and reference can be made to the World Water Development Report for 2021 dealing with water valuation (United Nations, 2021).

4.1 National level

Having set out all the caveats that apply to measuring and evaluating water use at operational levels in the main water use sectors, the aggregation of water use statistics at national level and the change over time is the fundamental requirement of SDG indicator 6.4.1. There are very few national economies who collect and analyse water use data regularly with a measure of consistency. For OECD countries, published reports are brief with very little analysis of water productivity (UK Government, 2019). This section summarizes some recent evidence from the United States, Australia and Jordan.

4.1.1 UNITED STATES

The trends in estimated water withdrawals from the USA (USGS, 2018) are indicative of the relative scale of changes in production processes in a maturing economy (see Box 8). The long-term trends in water use also have to be appreciated. The sectoral breakdown for the USA is illustrative of the relative scale of change in water use across sectors, compiled at the level of individual States. Overall trends in water withdrawals estimated by the United States Geological Survey (USGS, 2018) are able to establish that peak withdrawals in the late 1970s have been reduced, stabilised between 1980-2005 and then further reduced.

Most of this long term reduction since the peaked in the 1980s (some 34 percent) is attributed to changes in thermoelectric power plant cooling technologies, urban/municipal water-use efficiency programmes, and shifts in the industrial makeup of the economy. While irrigation withdrawals have shown a decrease over the period 1980 to 2010, recent trends are upward and it is volumes in thermo-electric generation and irrigation, which are significant – several orders of magnitude above those of other water using sectors. Important inter-annual changes in water use also result from the impact of droughts. Within the national picture, the detail at state level also has to be appreciated. For instance, in relation to California, the USGS (2018 p 54) report notes;

> **"Historically (1950–2010), surface water has been the primary source of irrigation water in California. However, groundwater was the primary source of irrigation water in California in 2015, likely as a result of limited available surface-water resources during the period of intense drought. In California in 2015, groundwater withdrawals for irrigation increased 60 percent from 2010, and surface-water withdrawals for irrigation decreased 64 percent."**

The trend in source switching prompted the California 2014 Sustainable Groundwater Management Act (SGMA), which calls for long-term groundwater overdraft to end and water-sheds to be brought into hydrologic balance. It is illustrative of changing water policy targets and the degree of adaptation across water consuming sectors that is needed to respond to climatic uncertainty, even in a well-buffered economy. One of the key strategies being pursued to meet the SGMA objectives is improvements in water-use efficiency that can reduce the amount of land that might have to be taken out of production. Whether such a combination of demand management, efficiency gains, and associated re-allocation are possible remains to be seen. Local stakeholders have until 2022 to begin implementation of Groundwater Sustainability Plans, which then have until 2040 to achieve sustainable water balances.

4.1.2 AUSTRALIA

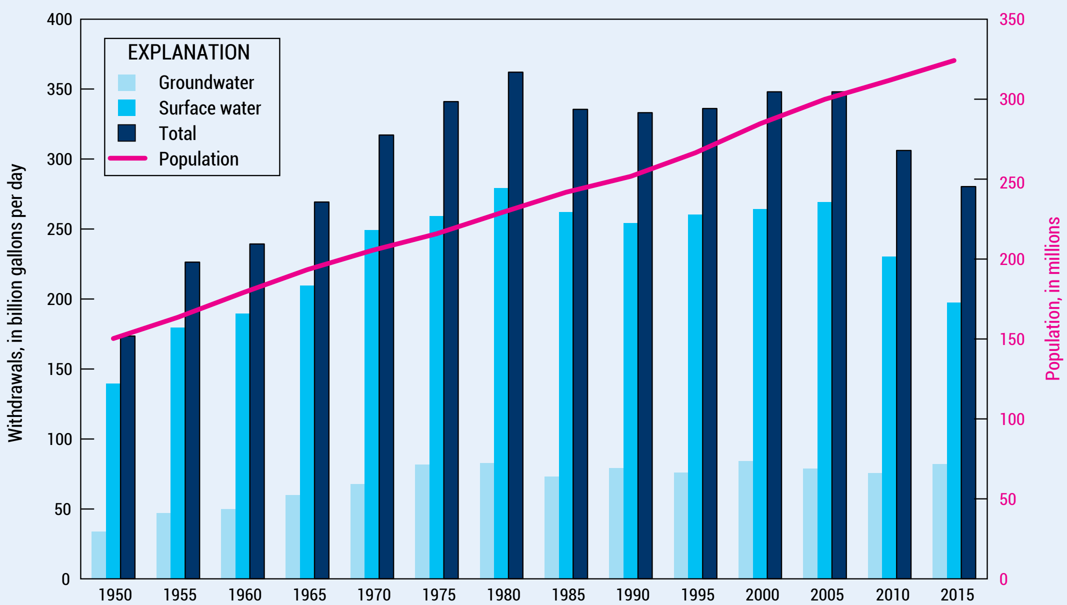
One of the more recent policy responses to water scarcity has been Australia's Commonwealth Water Act of 2007. As part of the Murray Darling Basin's 2012 Plan (Victoria State Government, 2019) (mandated by the 2007 Water Act), water rights were bought back by the Commonwealth Government in order to recover basin flows for environmental services along the basin. The socio-economic impacts of the 'buy-back' have been keenly watched by participating States (Victoria State Government, 2020) noting the rapid structural changes in the agricultural economy and farm incomes as a result of the 'buy-back'. The state of Victoria now recommends that any additional recovery planned by the Commonwealth Government "must only occur with neutral or positive socioeconomic outcomes for communities.". In practice, the implementation of the basin plan has proved controversial. After more than a decade of implementation, this recovery or 'buy-back' of water rights and the parallel subsidy of irrigation technology does not appear to have resulted in any measurable impact on in-stream flows (Grafton & Wheeler, 2018; Wheeler *et al*. 2020). In addition, detailed surveys in the state of Victoria (TC&A & Frontier Economics 2017) revealed evidence of the economic re-bound effect noted by Wheeler *et al*. (op. cit.). As one irrigator noted:

> **"We're saving water but we're being more intense and more productive. Because we're using It more efficiently and being more profitable that drives us to want more water to do more things. It has that driving effect. We gave water back but we went straight back to the market and bought it again."**

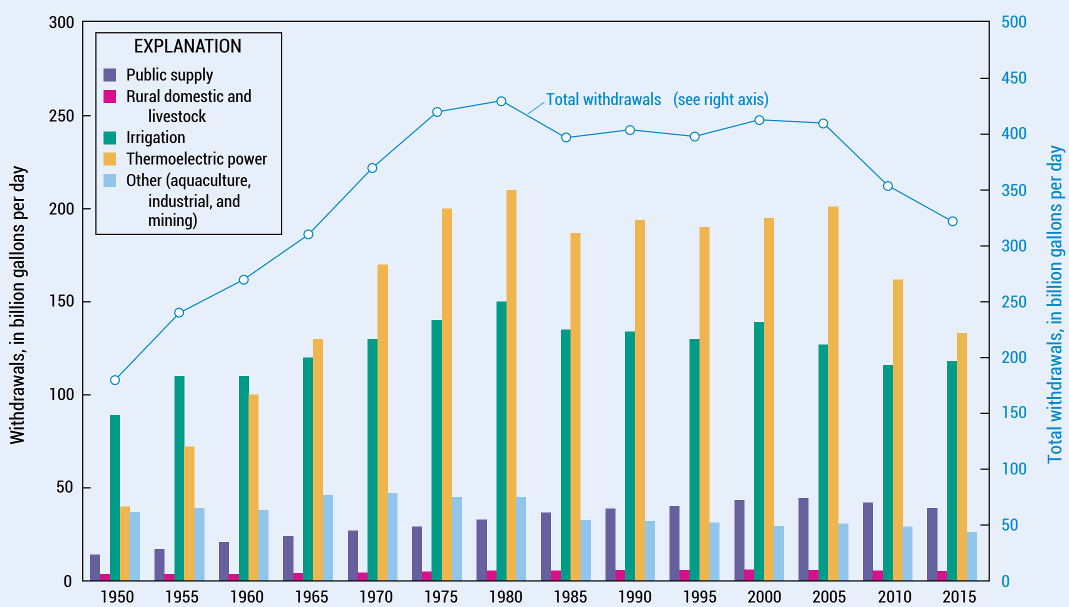
Source: TCA & Frontier Economics. 2017 p 6.

BOX 8: ESTIMATED WATER WITHDRAWALS IN THE USA 1950-2015

Trends in population and freshwater withdrawals by source, 1950–2015



Trends in total water withdrawals by water-use category, 1950–2015



Source: USGS/World Bank, 2018.

This example highlights the relevance of accompanying socio-economic and environmental policies and the choice of compliance instruments including the operation of water markets (Seidl *et al*. 2020). At the very least, technical 'fixes' to water scarcity problems need accurate measurement of the resulting surface and groundwater flows and a stronger approach to regulatory compliance. What might be apparent on paper (the return of water entitlements) does not necessarily translate to reductions in agricultural water withdrawals.

4.1.3 JORDAN

Analysis of data for Jordan (FAO, 2018a) indicates the state of play in a country facing severe water scarcity and coping with large refugee populations and why the reporting and accounting of water use has to be approached with care. Table 3 gives the broad partition of water use in Jordan based on Ministry of Water and Irrigation (MWI) estimates of 'use' for 2015 and 2016 to illustrate the annual variation that is reported across sectors and source of water. It should be noted that 'use' is not defined by MWI nor distinguished explicitly from withdrawals from watercourses, canals or aquifers. In the case of municipal/industrial use, the figures are assumed to represent retail water sales or metered abstraction from boreholes (and would have to include non-revenue production water to obtain groundwater withdrawals). In the case of agriculture, the estimate of groundwater 'use' is probably calculated on the basis of net irrigation water requirements set by MWI and reported) as such while surface water deliveries are assumed to equate to 'use' and need to be adjusted upward by canal operation 'losses' and conveyance inefficiencies to obtain surface water withdrawals.

Considering the expansion in irrigated areas since 2007, a commensurate increase in agriculture water use and withdrawals would be expected. Figure 4 plots the growth in areas equipped for irrigation against reported "agricultural use". But according to MWI statistics, agriculture's use has remained more or less constant for the past 10 years (508.6 MCM in 2006). With 90 percent of its population now

TABLE 3: COMPARISON OF WATER USE: 2015 AND 2016

Water Use for 2015 in (MCM)				
Uses	Surface Water	Groundwater	Treated Wastewater	Total Sector Use
Municipal	124.00	332.50	0.00	456.50
Agriculture	146.00	237.60	130.80	514.40
Industry	4.00	31.00	2.20	37.90
Total	274.00	601.80*	133.00	1 008.80

Source: MWI Jordan Water Sector Facts and Figures 2015 (http://www.mwi.gov.jo/sites/en-us/default.aspx) *(MWI rounding)

Water Use for 2016 in (MCM)				
Uses	Surface Water	Groundwater	Treated Wastewater	Total Sector Use
Municipal	123.75	333.15	0.00	457.00
Agriculture	155.00	237.60	134.24	547.20
Industry	3.00	31.00	2.10	32.50
Pastoral	7.0	0.63	0.0	7.6
Total	288.75	618.95	136.34	1 044.04

Source: MWI Presentation, FAO/SIDA workshop, Cairo October 2017.

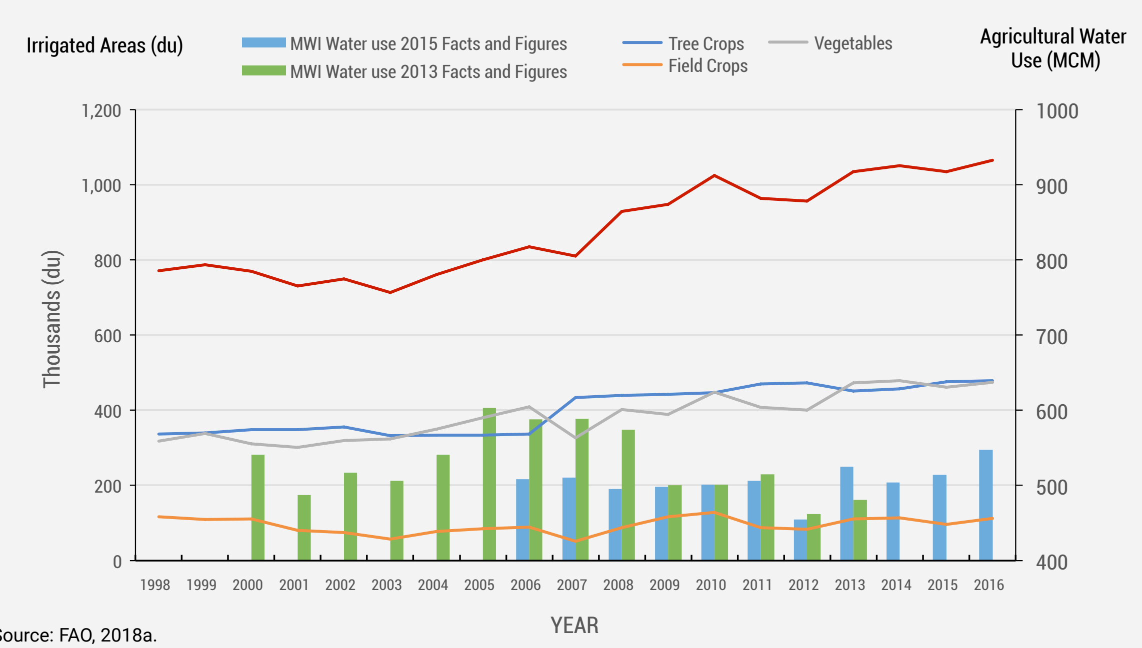
leaving in cities urban, urban use has grown from 291 MCM in 2006 to 456.5 MCM in 2015 while industrial use has remained more or less constant at around 40 MCM over the same period. This suggests that out of approximately 1 000 MCM total 'use', municipal water supply (domestic) will soon reach parity with agricultural use. That agricultural use is reported to have remained constant while irrigated areas have expanded by some 240 000 du (24 000 hectares) would suggest that overall water productivity has increased. This may be the case for some crops exhibiting yield growth but generally, this level of expansion would entail more withdrawals and more actual evapotranspiration.

4.2 Municipal water supply and wastewater treatment/reuse

Municipal water supply and wastewater utilities should have clear incentives to distribute volumes of safe, clean water as efficiently as possible across designated supply networks and continue to extend supply to the unserved communities. To do this elimination of treatment plant and leakage losses on the supply network is (or should be) the main focus utility operation in order to let the system run at design capacities.

Generally, the progress in making the network perform as designed is measured by managers and regulators as the difference between water produced and water billed at consumer metering points. This unaccounted-for water presents an obvious target for regulatory measures that can include subsidies to improve infrastructure and fines levied when leakage targets are not met (World Bank, 2006). Strategies to reduce unaccounted for water including leak detection and repair programmes are standard operations for water supply utilities in developing countries (World Bank, 2016a) and can form an important part of performance-based contracts (World Bank 2016b). Whether or not they are pursued

FIGURE 4: GROWTH OF JORDAN'S IRRIGATED AREAS (DOS) AND REPORTED AGRICULTURAL WATER USE (MWI FACTS & FIGURES)



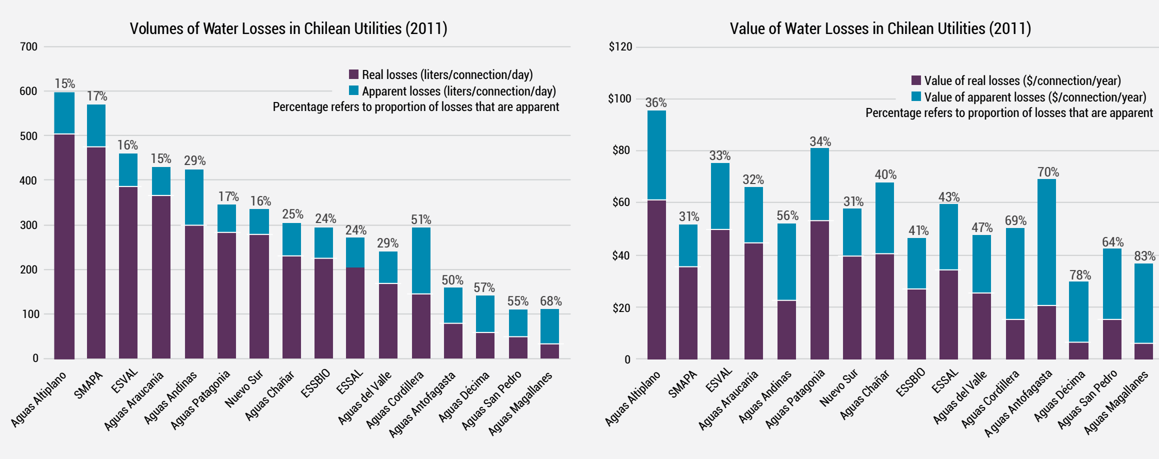
Source: FAO, 2018a.

with vigour may depend upon the effectiveness of economic and environmental regulation and this is where the detail of supply concessions and contracts comes into play. The use of contractual incentives to make efficiency gains and reduce unaccounted for losses and pollution has had mixed results. For instance, the experience of the UK regulator (OFWAT) and Environment Agency in stemming unaccounted for water and discharges of untreated sewage by private operators has pointed to the high level of executive pay and shareholder dividends at the expense of re-investment in infrastructure operations (Hutton, 2020).

However, sometimes the target is not so obvious. Figure 5 indicates the scale of real and commercial (apparent) losses in volume and value for a set of regulated private utilities in Chile in 2011. Although the volume of commercial losses, such as meter registration, may be small, the value in retail revenue is very high so that chasing physical losses can become less attractive compared with tackling the commercial losses.

On the retail side of the water meter, incentives change, and domestic/commercial customers have interests in tracking water use and making efficiency savings to reduce water bills. The on-site management of supply infrastructure, processing (including cooling) and waste streams can in many cases halve costs of supply and effluent charges (WRAP, 2013). Rising block water tariffs to curb levels of consumer water use are usually combined with public information and awareness campaigns, mediated by national regulation to protect vulnerable and poor consumers. Manufacturer standards for energy and water ratings for household appliances are also part of consumer and environmental regulations. The degree to which such demand measures are effective is variable but there is evidence that these are scale dependent (Maggioni, 2015) with larger utilities more effective at taking demand management to scale. In cases where water supply shock brings about emergency drought measures, intermittent supply or capping of use and eventual rationing of water for essential human needs have been deployed.

FIGURE 5: VOLUME AND VALUES OF WATER LOSSES IN CHILEAN WATER UTILITIES IN 2011



Source: World Bank, 2016.

In municipal supply systems physical water scarcity enforced reductions in water distribution as emergency measures are frequently observed in arid settings or where population demand has outstretched the capacity of the system (examples include Cape Town and Mexico City). Keeping water supply systems fully pressurized is a public health priority to avoid intake of polluted shallow groundwater and supply managers are reluctant to reduce pressures and cut supplies altogether to avoid this. As a result, many leaky systems are run at design pressures to avoid influx, despite significant losses of treated water to the system.

Leaks or losses at the retail end of systems (beyond the point of metering) can also be significant and running cisterns are often quoted as an example. Water conservation measures such as shower head reducers or cistern 'bricks' are used frequently and regulated new build housing or retrofitted sanitary ware can be used to reduce water use and result in efficiency gains so long as they do not impair domestic hygiene standards. For water using appliances such as washing machines and dishwashers' manufacturers are now obliged to certify energy consumption and water use. Along with water saving devices in showers and cisterns, water regulators are urging personal use of water to be reduced in order to slow the overall rate of growth of water supply and extend service to more new additions to the supply network (e.g. UK Environment Agency, 2020). In practice this regulation may be counter-intuitive to commercial suppliers of water who need to see revenue volumes maximised or even epidemiologists who want to see copious amounts of water used to promote domestic hygiene.

The recirculation of water supply through wastewater treatment and downstream dilution plus further abstraction has been a common feature of many intensively developed river basins. Some wastewater treatment plants for example in Victoria, Australia have managed to attain net zero losses – no additional water needs to be imported to run the treatment process (Low *et al* 2015). The conversion of urban wastewater streams into dedicated re-use streams in agriculture is gaining traction in water scarce settings (FAO, 2010) and an example of relevant water account for Jordan is given in Box 9.

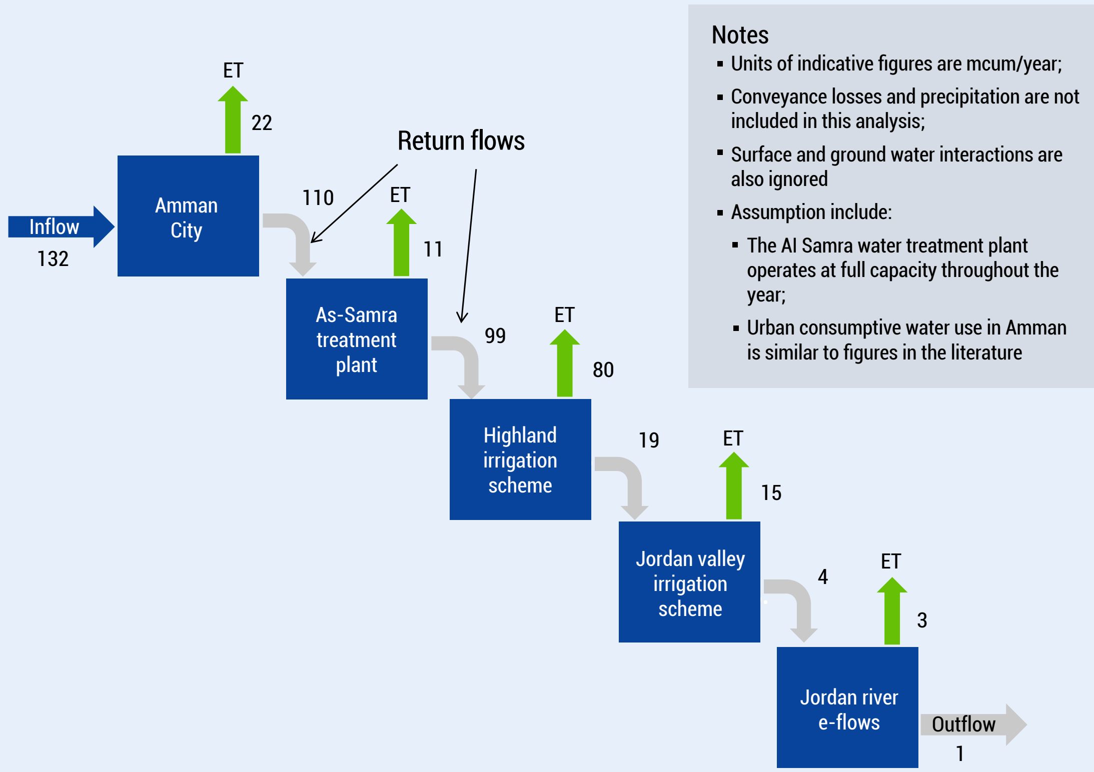
The products of wastewater treatment are multiple (Figure 6). The World Bank has recently taken stock of Latin American experience in wastewater reuse (World Bank, 2020) and makes the point that the levels of investment and degree of water quality management are such that such initiatives require sophisticated hydro-economic planning models to locate and design the necessary infrastructure.

4.3 Industrial bulk users including thermal power production

Regulatory agencies and trade associations give advice on resource use efficiency and may prompt industries to undertake audits of energy and water use. For example, Liu *et al*. (2020) point to modelled estimates of water-use efficiency across China (Figure 7) indicating some room for efficiency gains in industrial enterprises but also the progress made in wastewater recycling within industrial units.

The large volumes of water used by thermo-electric for energy generation have already been mentioned. In the case of the United States the volume of withdrawals for power plant cooling has, until recently, eclipsed withdrawals for irrigation (see Box 8). The 34 percent decline in thermo-electric water withdrawals since 2005 is attributed to the adoption of recirculating cooling systems as

BOX 9: JORDAN: TREATMENT OF MUNICIPAL WASTEWATER FOR AGRICULTURAL RE-USE IN JORDAN



Source: FAO Water Scarcity Programme RNE/SIWI http://www.fao.org/neareast/perspectives/water-scarcity/en/

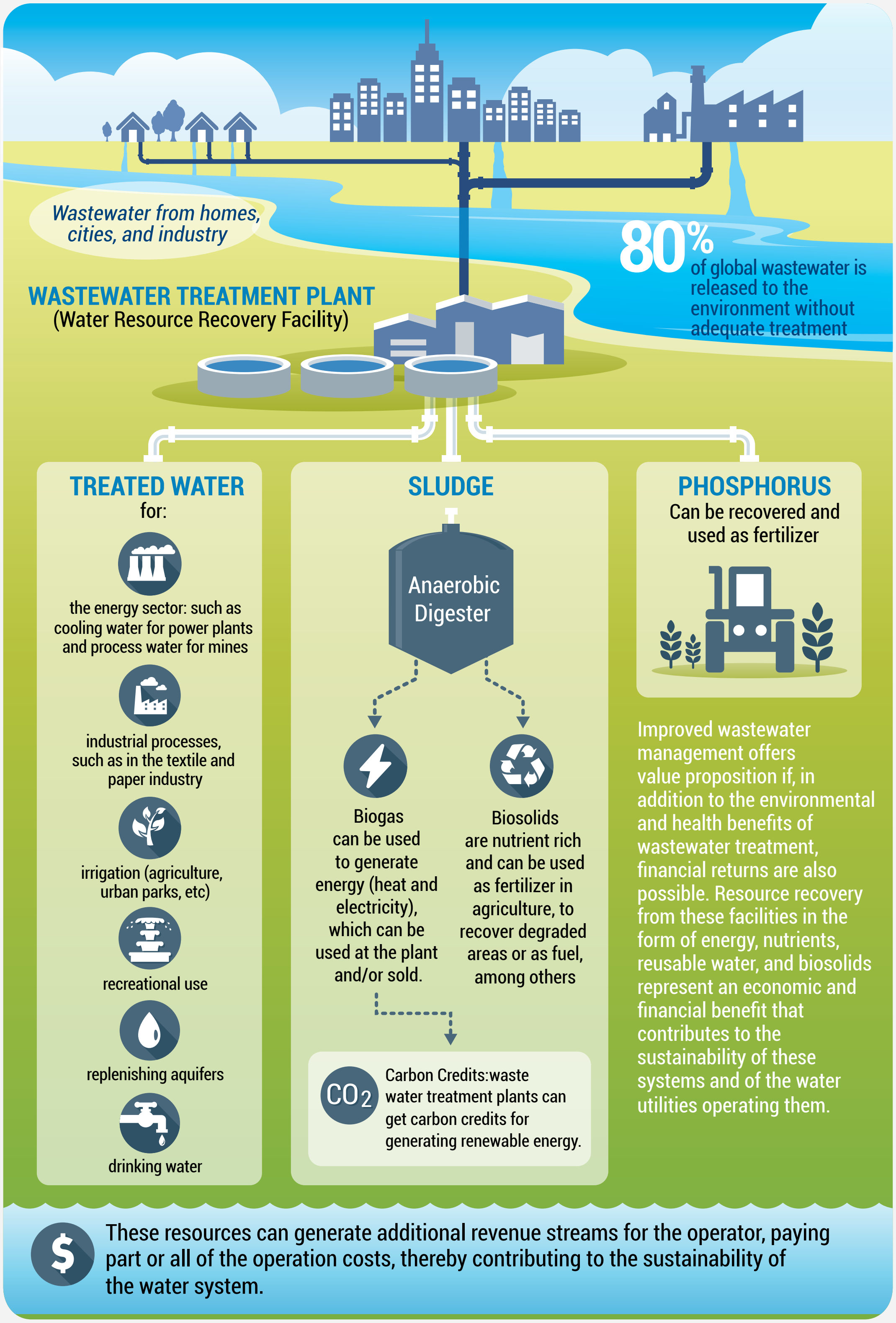
opposed to once-through circulation although the re-circulation has increased evaporative losses within plant operations (USGS, 2018).

Hydropower dam operation in tropical climates can also be optimized to minimize evaporation particularly if seasonal pumped storage is compared with conventional dam storage but the economic decision making required to evaluate the benefits and costs of such design and operation are not trivial (Hunt *et al*. 2018).

4.4 The mining industry

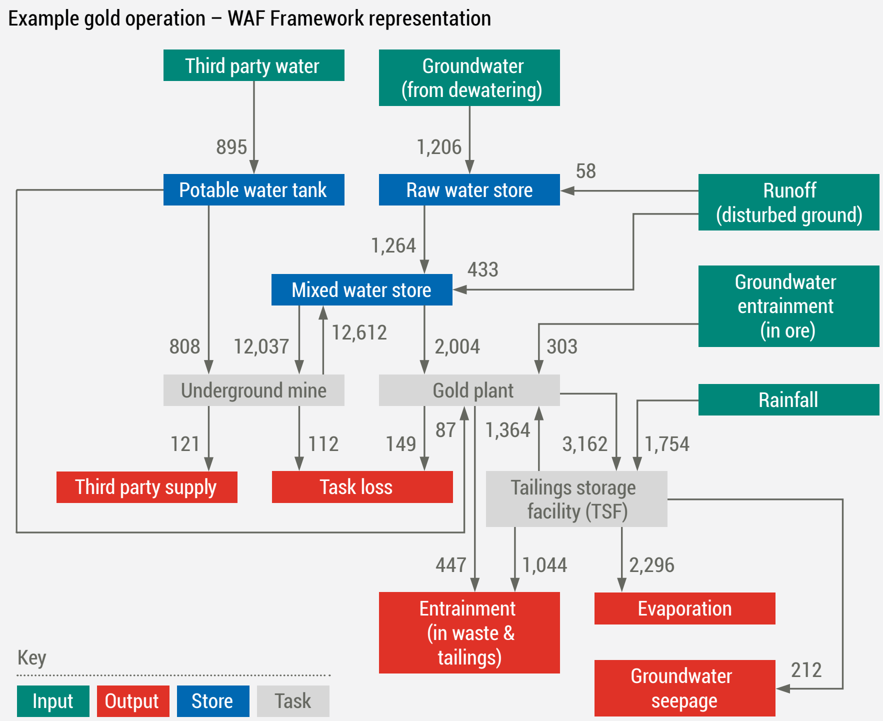
The mining industry is a particular case since it can withdraw large amounts of groundwater through de-watering operations while also using high volumes to process and leach mined material. Estimates of freshwater withdrawals by the non-fuel mining industry are estimated to be in the order of 7-8 km^3/yr with phosphate, copper and gold accounting for 75 percent of withdrawals (Gunson, 2013). The risks associated with the storage and treatment of mining waste and effluent are all too evident when tailing dams fail but the economic externalities arising from mining in arid areas in particular may be less apparent. Dewatering of working mines can produce large volumes of groundwater that needs draining away from the cone of depression around the mine (see Figure 7). In the case of the fracking industry, re-injecting groundwater to hydro-fracture oil shale also involves mobilisation of high volumes of

FIGURE 6: MULTI-FUNCTIONAL WASTEWATER TREATMENT



Source: World Bank, 2018d.

FIGURE 7. MINERALS COUNCIL OF AUSTRALIA WATER ACCOUNTING FRAMEWORK (WAF) EXAMPLE



Source: ICCM, 2017.

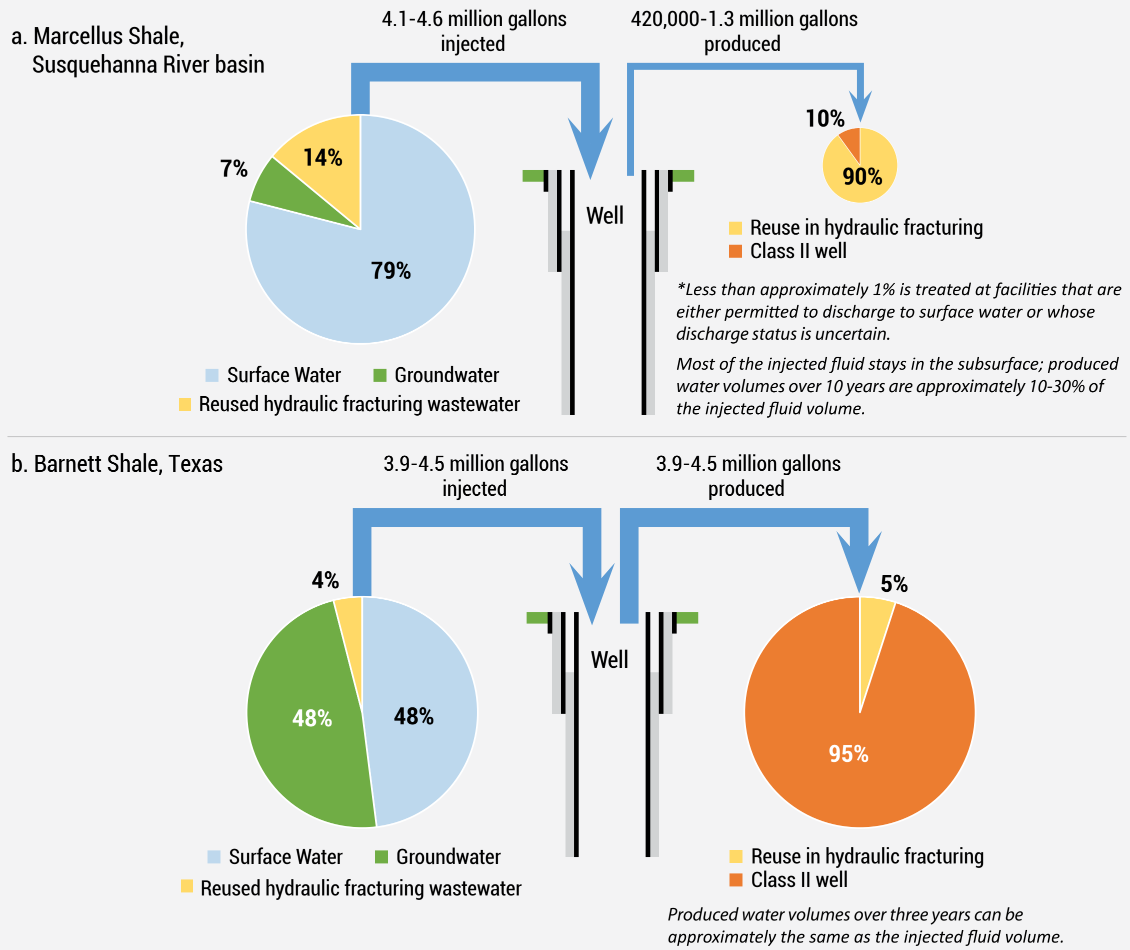
freshwater, which are subsequently re-injected with chemical agents and sand added. The impacts are notable and regional contrasts in sources of freshwater and ultimate disposal can be significant (US EPA, 2016: Figure 9).

4.5 Rural water supply

Dispersed rural water supply and sanitation services may account for very small volumes of water withdrawals in national water use accounts but they are one area where adoption of water and energy efficient technology standards can make a difference in delivering reliable and continuous supply service to poor and vulnerable populations. Keeping costs down and infrastructure standards up is a major concern, particularly when use efficiency across local networks of storage, treatment and reticulation is a priority. At catchment level, access to limited supplies of high-quality groundwater is easily compromised by intensive pumping for irrigation and pollution of local aquifers from agricultural drainage and pesticide application (FAO/IWMI, 2018).

There is limited data on water-use efficiency in diagnostic reports of rural water supply service. The overall concern is with allocation of financial inputs to deliver water services (e.g. World Bank 2017). In addition, FAO (2008) highlighted the range of rural livelihood dependence on water access in sub-Saharan Africa in order to target investments related to water management but as a package measures to enhance land productivity. Equally, micro-economic analysis of water productivity and rural poverty in mixed crop-livestock systems has been attempted (Clement *et. al* 2011), but also points to the

FIGURE 8: HYDROFRACTURING WATER USE COMPARISON USA.



Source: US EPA. 2016.

difficulty in isolating the specific or measured contribution of efficiency gains. When such local scale mosaics of multiple water use systems are evaluated (Van Koppen *et al*, 2006) it is clear that access to freshwater generates such a large and diverse stream of social and economic benefits that even if a strict comparison of water-use efficiency or productivity gains may not be possible, the data generated can inform planning and priority setting.

4.6 Agricultural water management

Agriculture's use of freshwater, whether it has been efficient or not, has been a widely debated point of contention between competing economic sectors as much as academics and researchers. The debate over terminology and inclusion of specific measures of flow and evaporation in technical efficiency and economic productivity calculations continues (e.g. World Bank 2018a). Indeed, many policy initiatives (including subsidies for hardware adoption) have focussed on irrigated agriculture in the expectation that overall water productivity could be substantially improved, and agricultural water withdrawals could be reduced and re-allocated as a result.

4.6.1 RAINFED AGRICULTURE

Productivity increases in rainfed agriculture through soil moisture retention and seed selection/agronomic adjustments are a major concern for global food security particularly under climate change (Rost *et al*. 2009; Jargermeyer *et al* 2016; Magombeyi *et al*. 2018). But since most rainfed crops are evaporating at or near levels for natural climax vegetation, the potential for reductions in actual evapotranspiration is negligible. In fact, higher cropping intensities will deplete soil moisture at faster rates and reduce downward percolation and groundwater recharge. It is also important to note that at commercially viable yields, the relationship between biomass production and water consumption by crops is linear (Steduto *et al*. 2007). For these reasons the prospect of reducing water consumption in rainfed agriculture are limited apart from reducing cultivated areas that are consuming water at higher rates than natural climax vegetation.

Capturing rainfall through water harvesting structures has often been cited as route to generate 'new' water – to extend baseflow recession and maintain patterns of soil moisture availability. While the local impacts of such measures may appear positive, particularly in upland areas where drainage is rapid anyway, the cumulative impact downstream has to be appreciated and any economic gain upstream may need to be assessed against reduced flows downstream (Batchelor *et al*. 2003). However, farmers and communities in headwater catchments are often the poorest, have the lowest land capability, and may not be able to afford to install storage and irrigation. They may also have limited access to agricultural markets in remote locations. These issues can be played out at a large scale when disputes over winners and losers arise as a consequence of the introduction irrigation technology (MacDonnell, 2015).

4.6.2 IRRIGATED AGRICULTURE

The irrigated sub-sector has been pointed to as a prime area for water-use efficiency gains. The direct comparison of irrigation technology offered as far back as 1974 by researchers at IILRI (Bos & Nugteren, 1990 4th edition) gave impetus to a purely hydraulic (water volumes) definition of irrigation system efficiency. Indeed, the reduction in irrigation water 'losses' in conveyance canals through canal lining and modernization of operations have been a consistent policy and operational priority in economies reliant on irrigated agriculture. However, improving the distributive capacity of the systems and giving more reliable service to tail-enders has resulted in increased withdrawals as cropping intensities have risen and areas equipped for irrigation have expanded throughout the 20th and 21st centuries, from near 160 million ha in 1960 to almost 340 million in 2018 (FAOSTAT http://www.fao.org/faostat/en/#data/RL).

With the advent of pressurized irrigation, particularly from groundwater sources, government subsidies to farmers wishing to convert from flood irrigation to sprinkler and drip technologies have become widespread in the hope that improvements in irrigation efficiency at scheme level would reduce withdrawals – whether from surface or groundwater sources - and allow water to be distributed to other productive sectors or retained in the aquatic environment. This aspiration has been modelled on the assumption that all inefficient surface irrigation systems could be replaced by sprinkler or drip systems (Jagermeyer *et al*. 2015). However, the current extent of sprinkler and micro-irrigation technology adoption is currently reported at some 46 million ha (AQUASTAT http://www.fao.org/aquastat/en/databases/maindatabase/) but has also been estimated at some 51 million ha (ICID, 2012). This is just 15 percent of the total global area equipped for irrigation and the adoption of such precision irrigation is limited to areas of land on which the soils, technology and crop type happen to be suited. Therefore, a presumption that a complete transition to pressurised irrigation can be made and withdrawals significantly reduced would appear counterfactual.

Studies that have looked at attempts to conserve water through adoption of precision irrigation include China (Kendy *et al* 2003), Chile (Scott *et al*, 2014), India (Birkenholtz, 2017), Mexico (Carrillo-Guerrero *et al*. 2013), the United States (Ward and Pulido-Velazquez, 2008; Pfieffer and Lin, 2014), Morocco (Molle and Tanouti , 2017), Spain (Lopez-Gunn, 2012) and Australia (Grafton and Wheeler, 2018). This evidence indicates that any efficiency gains made through water conservation programmes, including the adoption of irrigation technology, can make improvements in the delivery of water to the root zone and boost agricultural water productivity. However, this may not result in reduced withdrawals or the desired re-distribution of benefits. Instead, the water savings tend to be internalised by farming units who intensify crop production and expand areas under more efficient irrigation technologies also suited to higher value crops, thereby increasing their evaporative consumption of water and reducing return flows and aquifer recharge. This amplifies the example from Australia given in section 4.1.2 and points to existence of an economic 're-bound effect' sometimes referred to as the "paradox of irrigation efficiency" (Grafton *et al*. 2018) .This would suggest a general policy failure to cap water use and re-direct saved water to produce the desired outcomes that prompted the intervention in the first place, whether re-allocation or environmental protection.

Other policy instruments such water permitting systems and regulated water market transactions, or caps on water abstraction may act as incentives for adoption of new irrigation technology and cropping systems, which may reduce volumes of applied water but can also result in higher pollution loads (García-Garizábal & Causapé, 2010). Such incentive-based systems usually exist within a tangled array of social and economic policy instruments so that impacts may be hard to isolate and prove on paper and in the field.

The conclusion reached is that increases in water productivity can be made as a result of efficiency programmes in agriculture, but that there is little evidence of water saved being 'freed up' for use by other sectors, including environmental flows, largely because of a failure to physically re-direct the saved water in line with policy intent. Compliance at the point of withdrawal would seem essential but has to go hand-in-hand with the capacity to measure and account for return flows, and policy instruments to conserve quality and volumes downstream of irrigated areas.

4.6.3 FORESTRY

Forests are an integral component of the water cycle account for over 30 percent of terrestrial land cover and influence streamflow regulation, foster groundwater recharge and contribute to atmospheric water recycling, including cloud generation and precipitation. For example, roughly half the evapotranspiration of the Amazon and Congo basins returns as rainfall over land (van der Ent *et al*., 2010), highlighting the role of forests in rainfall generation as a form of natural water-use efficiency at scale. The regulatory services of forests, reducing surface runoff and improving soil infiltration and soil water retention are important in humid catchments as much as areas prone to water scarcity and drought (Ellison *et al*, 2017). Similarly, dryland areas with 5-10 percent tree cover in Burkina Faso, experienced five times higher soil infiltration than in open areas, improving water availability for ecosystems, agriculture and communities (Tobella *et al*. 2014). The conservation of forested land is generally seen as making a positive impact on the hydrological cycle, particularly if conserved as primary forest (FAO, 2020b).

There is less consensus over the management of forested land and the role of afforestation. In some climates, afforested land is classed as a water user. Over 70 years of research in South Africa has shown planting grasslands and shrublands with deep-rooted and fast-growing evergreen trees (primarily eucalyptus and pines) significantly reduces streamflow. In some cases, flow impacts are seen as soon as two years after planting (Van der Zel 1995) and mature eucalyptus was shown to transpire more water than the average annual rainfall since they are perennial and transpire water in winter and being deeper-rooted trees can exploit a greater depth of available soil moisture, whereas grasses are dormant in winter.

5 Where and to whom water-use efficiency matters

The examples given in section 4 apply to the main water using economic sectors but tell little about where and who stands to gain or lose. How water is used and consumed across landscapes and patterns of settlement results in depletion of flow or storage and in a set of benefits to those who can capture the water. Nonetheless, it also represents an opportunity cost to those who have little or no access to water or receive polluted water downstream or down piezometric gradients.

If the objective is to 'save' water, it may be clear that leakage of high-quality treated water from poorly fitted and maintained water reticulation system represents a loss to the system and a loss to those who might have benefited – consumers and operators alike. If the system is inefficient in terms of water and energy consumption and investment in leak detection, repair and maintenance will immediately improve system efficiency. But in the case of an aquifer that is being used to grow low-value crops with very high-quality water with irrigation equipment that induces high levels of evaporative/aspersive losses, many more considerations of 'efficiency' come into play. How much drainage is actually re-circulated in the aquifer? Is drainage degrading aquifer and groundwater quality? Would more economic efficiency be gained by conserving the high-quality groundwater for potable use?

These details of water accounting and auditing notwithstanding, competition for freshwater and freshwater quality is intense among the main sector users even in humid river basins.

The large sector users such as municipalities, power generation utilities and commercial farming units may be adept at defending their allocations – on paper and in practice. However, the dispersed rural communities and un-served urban poor have difficulty in maintaining access to even de-minimus withdrawals for basic human needs and subsistence (FAO, 2016b). Equally the 'demands' of aquatic ecosystems have proved difficult to protect particularly when return flows prove to be the main source of environmental flows. The key finding here is that improvements in water-use efficiency can free up water for other uses, but the reallocation of that water to the environment, other economic sectors, or disadvantaged communities requires explicit policy instruments and management decisions, all which may not be in place.

5.1 Spatial changes over time

When water use accounting is consistently applied and analysed the large-scale shift in water-use efficiency can become apparent as in the 5-year exercise carried out in the United State of America (USGD, 2018). The changing patterns of the main sector users can be picked out at the level of cities, industrial plants and concentrations of irrigated production. Water utility resource managers may also keep internal records of changing levels of network demand, leakage and billing to record patterns of urban growth and their own performance, but such records are rarely published. The response of water resource managers and consumers in times of drought tests demand management to the limit (Low *et al*. 2015; Maggioni, 2014).

The most evident changes in physical water productivity over space and time is given by the time series data illustrated in Box 7. At continental level, the highest water productivity is achieved in in rainfed areas. At national level, the boost given by application of irrigation is clearly apparent in arid areas where large centre pivot systems are easily identifiable (Box 7). The spatial distribution of the net primary productivity from natural vegetation and agriculture therefore gives an indication of the production advantage and potential benefits over time. It does not tell us directly who benefits but it does indicate where water conservation could make a difference or where storage of seasonal rainfall would give a production advantage. The non-stationarity of hydrological processes and important hydrological variables (Beven *et al*. 2016) are also important considerations given that prolonged periods of drought and episodes of intense rainfall can arbitrarily affect vulnerable populations.

National statistical accounts of water productivity for specific crops (e.g Sharma *et al*. 2018) can tease out relative performance of rainfed and irrigated production over the period for which the production data are gathered. But such studies cannot pinpoint where improved water-use efficiency by farmers will make a difference in the long term. They can only recommend that improved water-use efficiency form part of an agronomic package of measures to raise land productivity in general, or more critically in the case of India, where depletion of groundwater could be slowed down by moving away from crops with high water requirements. By contrast, the water rights information systems in the USA that have been up and running for long periods pinpoint/georeference points of diversion and location of water use. They also record relevant information in attribute tables.

5.2 Hierarchy in the basin – environmental consequences

For uses dependent on point withdrawals, overall water-use efficiency gains through re-use and recirculation in municipal/industrial supply systems may be driven by geographical position in the basin and relation to upstream and downstream users. Coastal cities have a different set of efficiency concerns compared with those cities capturing and treating freshwater in the headwaters of a basin. The environmental consequences for large scale river basins have been examined in some detail particularly since agricultural withdrawals and consumption have diminished flows significantly and threaten to 'close' river basins altogether (Molle and Wester, 2009).

Sorting out where water-use efficiency can be improved locally is one thing, but deciding the circumstances in which water-use efficiency comparisons can drive water policy initiatives is another. Determining precisely where the distributive net benefits from efficiency gains can be realised involves a complex trade-off across communities and sectors and typically involves the development of hydro-economic models (Ward and Pulido-Velazquez *et al*. 2008; Harou *et al*. 2009). Translating the results of such modelling into implementable policy initiatives that involve adjusted water allocations, reduced water use in some cases and pollution regulation still remains a policy challenge.

For a domestic water user of surface water flow/storage, living downstream of an industrial zone or a heavily consuming irrigation project, the political power deployed in basin allocation process may determine welfare in terms of reliability of supply and water quality. Equally, for local water sources that may be multi-use and multi-functional, local political tensions between those wanting large volumes of groundwater for irrigation and those needing comparatively low volume of high-quality groundwater for domestic purposes are manifest in many subsistence economies (e.g. Venot, 2009). The implications for poor communities living in upstream highland and mountain settings have already been highlighted. These communities may be marginalized and unable to lobby for investments to improve their local water service operations or payments for environmental services as an alternative to intensive local use of water or forest resources. A more progressive approach to water 'tenure' as opposed to formal administrative water use rights has been advocated by FAO (2016b) to overcome such disparities.

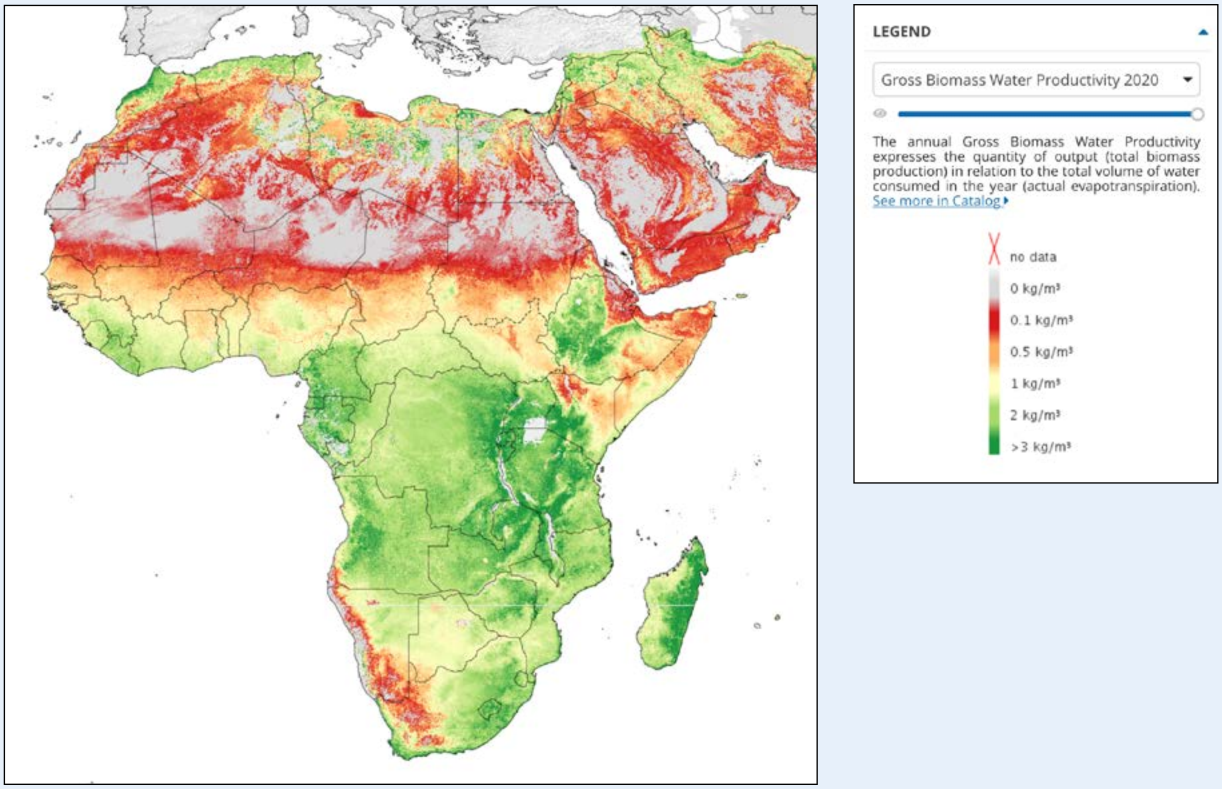
In post-industrial economies, the tension may be over water quality to sustain local biodiversity. The individual consumer in developed economies is well aware of energy saving devices and to a lesser extent on water saving devices to reduce individual consumption. Nevertheless, while generated energy is generally completely consumed at the point of delivery, in fact very little retail water is consumed and most water utilities calculate that all water delivered to a consumer also has to be drained and treated. For many domestic consumers whose drainage is treated, sewage charges often exceed water supply charges on consumer water bills. For commercial or industrial users of water cases may be different depending on whether the enterprise treats its own wastewater to an agreed environmental standard or simply evaporates supplied water – cooling towers or irrigation/landscaping.

5.3 Distribution of rural poverty

Away from the concentration of urban/industrial demand and water pollution, efficiency concerns may be of another order and related very much to levels of access across a contested landscape (FAO 2016b; Trottier, 2019). At the micro-economic level of a firm or a farm, it may be possible to determine water-use efficiencies by separating out or keeping constant all other factors of production and derive a notional water productivity at that locality. On that basis, production can be improved to bring about a desired or optimal level of production with respect to a quantum of water. Does the producer spread that quantum of water across the whole production site in one go or concentrate the water input on a limited area and release or drip-feed the process over time? This would be the typical dilemma of an irrigation farmer when water inputs are constrained by either physical scarcity or financial cost.
For instance, the methodology employed in the 2008 FAO study of rural livelihoods (FAO, 2008) could now be targeted with more precision and a higher chance of sustainability over seasonal and annual variation with the aid of the biomass water productivity mapping illustrated in Box 10.

The benefits and costs of water-use efficiency measures in agriculture do need careful appraisal. For instance, productivity gains in rainfed agriculture will involve more efficient use of available soil moisture, but investment in treatment of land and cultivation practices may still prove risky for farmers if there is no rainfall. This risk is expected to increase under climate change. Then the adoption of some forms of precision irrigation, notably drip lines and subsurface drip lines, may offer more efficient delivery of water to the root zone, but they also require high levels of maintenance. This applies to the filtering of solid particles and the prevention of clogging from precipitation of nutrients and high levels of dissolved solids.

BOX 10: GROSS BIOMASS PRODUCTIVITY

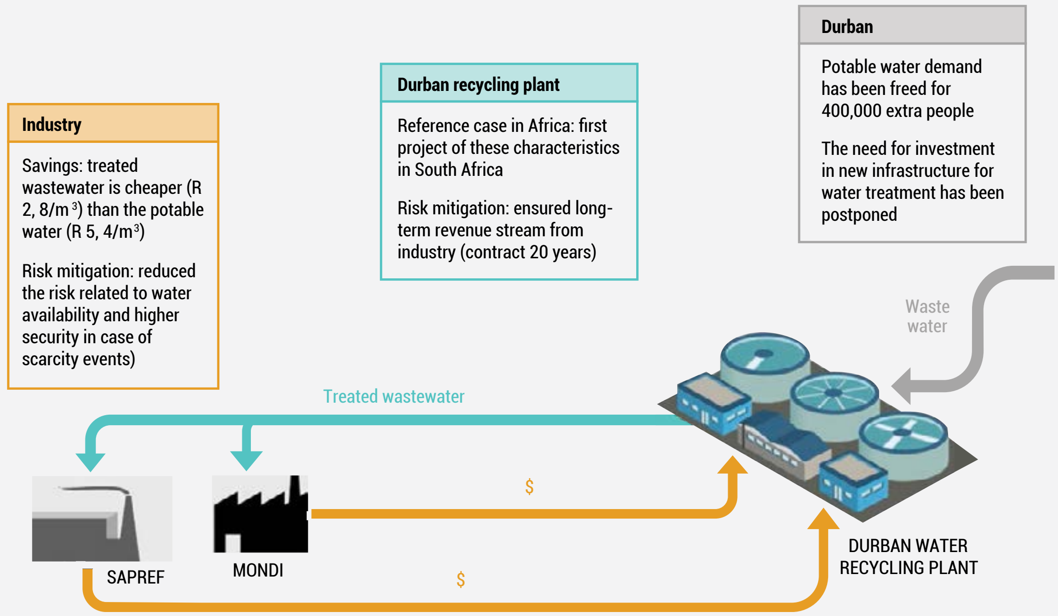


Source: FAO, 2021. http://www.fao.org/in-action/remote-sensing-for-water-productivity/en/

5.4 Distribution of urban poverty

The public health impacts of urban water poverty are far reaching in rapidly growing urban centres (Adams *et al*. 2020). The juxtaposition of extreme water wealth (swimming pools and irrigated lawns) and dense urban slums with no piped water and sanitation service can be striking. These unserved urban and peri-urban communities have prompted much of the concern in the SDG target. The persistence of urban water poverty and consequent tension over access to water services may point to institutional failures rather than physical water scarcity (Barraqué, 2012). The degree to which water-use efficiency measures can help extend network capacity and more reliable service to those experiencing interrupted supply or loss of pressure depend upon institutional commitment and infrastructure investment. An indication of the type of sophisticated economic and contractual decision making that is necessary in order to ‘free up’ water for expanding urban centres is given in Figure 9. Such examples illustrate that even if leak detection and repair continue, the required jump in volumes may come from creating ‘new’ water through wastewater recycling.

FIGURE 9: DURBAN WASTEWATER RECYCLING BENEFITS



Note: Treatment plant image is by Tracey Saxby, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).

Source: World Bank, 2019.

6 Prospects for water-use efficiency gains

The examples of methods and practice in sections 3 and 4 point to the complexity of determining water-use efficiency gains. But until localised in the domain of use, appraisal of precisely where water productivity and water-use efficiency gains can be made becomes difficult without rigorous and frequent water accounting. Assessment of who benefits in terms of public health, income and environmental services can be straightforward in some cases (leak detection and repair in urban networks) but less obvious when benefits are highly distributed in agricultural landscapes across densely populated river basins. Nevertheless, there are indications of real prospects for gains at national level through water-use efficiency measures when the aggregate effect of changing patterns of water use can be measured (USGS, 2018).

6.1 Water withdrawals

The global trend in water withdrawals is still upward even if rates of growth appear to be slowing. As stated in the Background section of this Brief, the global trend can obscure examples of reduced withdrawals at national level that can be attributed to efficiency gains within specific sectors. There are few exploited river basins that can claim to be single use and single function and most cascades of water have multi-functions and multiple uses. Within these locally complex mosaics of water use, whether formal or informal, teasing out the evidence for real efficiency gains is not straightforward and not all water uses lend themselves to desired efficiency improvements.

A global goal of water-use efficiency might appear contradictory depending upon perspective. For instance, water policy in public health would generally encourage increases in per-capita supply and promote higher volumes of supply at the point of use. Equally, many styles of irrigated agriculture are designed to be run 'wet' in order to provide a range of agricultural and environmental services. In most cases, operational water budgets are not constructed upon the consideration of single factor productivity alone but have more to do with spreading hydrological and financial risk to obtain an outcome that is 'satisfactory' but not necessarily 'optimal' with respect to water inputs.

The use of repetitious, operational water accounting would therefore seem essential to localise water balances and reveal opportunities for net gains. Equally, the analysis of distributed economic and environmental impacts across the selected basin requires the development of hydro-economic models, which are data intensive and need to be maintained to attain credibility as a water policy analysis tool (FAO, 2016a).

At basin scale, the large users (thermal power generation, irrigated agriculture) are where the greatest scope exists. Crop water-use efficiency gains in rainfed agriculture through soil treatment can offer most scope by virtue of scale and while this will not reduce consumption, it might re-direct drainage to aquifers rather than runoff – a distributive gain. By contrast, the evidence from current policy initiatives to adopt more 'efficient' irrigation technology is mixed (Venot *et al*. 2017) and evaporative consumption is increasing as irrigated areas expand and irrigated production is intensified. While water productivity is expected to increase in rainfed and irrigated settings as agronomy improves, it cannot be assumed that this will translate into water savings at global level.

In large industrial complexes and municipal water utilities, stemming leakage of non-revenue water shows better prospects since even publicly disclosed levels of leakage are in the order of 15-30 percent. Bringing down such losses would first allow distribution networks to maintain design pressures and extend levels of water service in all parts of the network. Some diminution of raw water withdrawals could result but in many cases, urban utilities are expanding to cope with increases in customer numbers and per-capita consumption. At national scale, the adoption of more water efficient energy generation needs to be examined as indicated under the World Bank's 'Thirsty Energy programme" (World Bank, 2018d).

For water supply utilities, technical advances in pipe and open channel flow measurement are now making the real-time gathering of flow information to help monitor and automate water service deliveries (Liu *et al*. 2020) and even irrigation system distribution (Rubicon, 2021). The use of acoustic doppler techniques in locating leaks in pressurized systems are helping water utilities to reduce non-revenue losses.

Formal, regulated re-use of urban wastewater for certain types of irrigated crops (e.g fodder) is being adopted when driven by physical scarcity but this is on top of informal re-use that is happening anyway on urban fringes where wastewater streams are developed with minimal levels of treatment.

The prospects for efficiency gains for personal/domestic use are marginal given the high levels of water poverty in disadvantaged populations across the globe where public health policy is pushing for more per-capita consumption. Amongst the wealthier urban populations, evidence from the effectiveness of public awareness campaigns is that an initial reduction in per capita water use is soon followed by reversion to former levels of use.

6.2 Socio-economic impacts

Financing of infrastructure and demand management measures, including funding of water accounting procedures has become a priority in water scarce basins. Use of treated wastewater is expanding, but financing wastewater treatment plants in complex physical and regulatory settings will remain a challenge. The economic efficiency of subsidies for water technology improvements also has to be watched carefully to determine who benefits from the subsidy and re-allocations. There is a strong economic case for targeting the beneficiaries who stand to gain from improved water-use technologies that increase availability and protect marginalized groups (World Bank, 2017).

Contradictions can also occur in the application of water conservation measures depending upon governance arrangements for water allocation and supply (Molle, 2017). Commercial water supply utilities have a financial interest in raising revenues through the sale of retail water while also being obliged to buffer storage in their networks to cope with periods of low rainfall. National regulators may also require utilities to respond to drought or water conservation policy measures (Environment Agency, 2020) to reduce per-capita consumption – all of which can raise operation and maintenance costs (e.g. leak detection) and threaten revenue growth and eventually dividend pay-out. On wastewater management, the design and operation of sewage treatment plants may assume minimum dry-weather flows for efficient functioning of treatment and sludging processes.

6.3 Environmental trade-offs

The environmental benefits derived from reduction in water use and resulting withdrawals may seem clear if use is forgone in order to maintain desired baseflows and aquifer circulation. However, as infrastructure crowds in on river basins, trade-offs become inevitable (Hurford *et al*. 2020). For example, apparent efficiency gains resulting from a campaign of demand management may compromise the operation of wastewater treatment plants if flows are reduced below operational thresholds. Equally, reduced runoff and drainage induced by precision irrigation can allow concentration of nutrients and mobile pesticides (Olsson *et al*, 2013). As pressure on river basin resources, including groundwater storage, continues to build, the instrumental role of return flows and the quality of that flow will come under more scrutiny (FAO/IWMI, 2018). The scale and implications of this challenge have been examined mainly in relation to agricultural withdrawals (Molle and Wester, 2009). Any water-use efficiency measure therefore needs to be considered in parallel with impacts on environmental quality generally – not just the immediate impact on in-stream flow augmentation. This makes the determination of environmental flows a complex and sometimes contentious matter (Acreman and Dunbar, 2004; Acreman, 2016).

The range of nature-based solutions identified in the 2018 World Water Development Report (United Nations, 2018) point to the adoption of broad land-based interventions such as conservation agriculture which are essentially designed to maintain soil moisture availability to crops. While crop water-use efficiency and water productivity are enhanced as a result, the environmental trade-off is made against the water-use efficiency of the pre-development natural ecosystem. For instance, where conservation agriculture has been taken to scale, such as Brazil, this has occurred at the expense of the natural forest cover and associated soil functions (FAO, 2020b).

6.4 Climate goals

Water-use efficiency initiatives are being driven by trends in water scarcity resulting from changing climate regimes combined with population and economic growth. Adaptation measures have been examined in detail in the recent UN World Water Development Report on climate change and water (UNESCO, UN-Water, 2020) and the IPPC special report on land (IPCC, 2019) so that the broad range of interventions and associated investments do not have to be repeated here. It is sufficient to note that producers of water services and their users will still have the economic capacity to expand storage and consume more even under conditions of extreme scarcity.

Although climate mitigation opportunities linked to water-use efficiency may be less clear, the examples given in this Brief can amplify those findings, particularly with respect to climate adaptation. For instance, energy efficiencies gained in pumping water with modern variable speed drive pumps may simply encourage more pumping. Solar pumping of groundwater may be very energy efficient and have very low marginal costs, but the technology can still result in higher levels of withdrawal and higher levels of evaporative consumption. As noted by FAO, (2018b p. 26)

> **"The risk is that farmers will consume more water than they did before the introduction of solar powered irrigation systems, by:**
>
> - **applying more water in the field overall (for example, when shifting from deficit to optimal irrigation, or simply over-irrigating);**
> - **expanding the area of land under irrigation;**
> - **growing higher-value, but often more water-intensive, crops;**
> - **selling water to neighbouring farmers and communities."**

As with all environmental trade-offs, an understanding of how large users of land and water assess their specific production risk and profitability would seem essential. Responses to their prime economic drivers may outweigh responses to climate forcing over the short term when input levels can be adjusted to keep profitability at satisfactory margins.

Conclusions

Global water withdrawals may be slowing but the pressure on freshwater resources will not relax

Patterns of water use are intensifying in urban and rural settings and their respective economic sectors. Population and income growth dictate that pressure on water withdrawals will not relax – there will be more water use and proportionally more water consumption through evaporation as agricultural production intensifies. The rate of increase is expected to slow as population growth slows and demand for food production becomes saturated, but global demand for freshwater will continue to increase even as per capita withdrawals decline. Given this imperative, local water-use efficiency gains that result in the spread of net benefits can be expected if appropriate governance arrangements are in place, but local gains risk being obscured by the use of aggregate indicators of national water use.

The SDG water-use efficiency indicator has limitations

Against the rise in demand for water globally, the SDG indicator 6.4.1 assumes that more can be done with less within sectors to contribute to the long-term sustainability of water use and allow some form of redistribution toward those whose consumption for basic human needs in hygiene and nutrition is currently very low. As calculated, the 6.4.1 indicator compares economic output with total water withdrawals. It does not provide an indicator of water use (inputs) in the production of goods and services or the distribution of social benefits derived from water. The gross value added (in effect, gross domestic product or GDP) is skewed toward services and industry where monetary values are high and water use comparatively low. The agriculture sector by contrast 'suffers' in the weighting scheme by contributing low commodity values but very high withdrawals. In this sense, the combination of the three sectors weighted by water use obscures comparison of the relative performance of specific sectors and these sectoral contrasts may not be reflected in SDG 6.4.1 indicator sufficiently to guide national policy measures.

There is no substitute for field-based water resource monitoring – including quality of return flows

The need for direct measurement of surface flows and groundwater piezometric heads will not disappear even as remote sensing of land cover and related geophysical signals improves. Technology advances in open-channel water metering and gate operation will continue to advance adoption of on-demand irrigation and industrial canal service delivery. It is not possible to address conservation of water volumes without a consideration of water quality changes along the cascade of use, consumption and re-use. In order to obtain positive gains, water-use efficiency measures need to be evaluated against impacts on downstream water quality in drainage return or wastewater flows. As water re-use intensifies, environmental trade-offs are inevitable and the means to account for water quality changes resulting from efficiency measures will need to be monitored with more frequency and precision.

Operational water accounts will become central to the application of water-use efficiency measures

Water balances of individual sectors need to be unpacked and detailed operational water accounts for specific water use domains used to accurately track performance. Measures of consumption and measures of return flows and return flow quality are important for all sector uses when discussing water-use efficiency. Water productivity measured in a specified domain can be an important indicator of physical and economic performance when water is scarce, and the benefits derived from water withdrawal and management are significant.

In practice, the application of water-use efficiency measures has had mixed results.

Some notable gains in water-use efficiency have been made, particularly in the generation of thermal energy, and incremental gains in manufacturing processes and leakage control in municipal water supply systems are evident. The agriculture sector is more problematic. While the adoption of technology, including precision irrigation, has boosted the productivity of agriculture, there is little evidence of water-use efficiency measures freeing up water for other uses or being returned to the environment as recharge or drainage. This is particularly the case in water scarce countries where it is observed that irrigated agriculture tends to 'internalise' efficiency gains through intensification and expansion of irrigated areas. Consequently, determining who will benefit from the adoption of water-use efficiency measures will be difficult without explicit allocation policies to direct efficiency gains to desired beneficiaries.

The technical scope for water-use efficiency gains exists and support to technology adoption will need to be expanded.

The technical scope for water-use efficiency to be improved locally and taken to scale will continue to improve in all economic sectors and operational water accounting will be needed to validate any claimed efficiency gains. Whether such initiatives translate into water savings at a level in the hydrological system that benefit unserved communities and keep aquatic ecosystems in play over the long term will depend upon the governance of water resource allocation. The economic and political cost of improved technology and governance of water allocation needs careful appraisal prior to any public investment. It will only be possible to slow the growth of water withdrawals or make desired re-allocations if explicit water policy instruments and management decisions are in place. The continued examination of policy provisions to support adoption of water-saving technology will be necessary if capacity building initiatives and awareness raising are to trigger the necessary behavioural change. Understanding the drivers of water use at the outset is fundamental.

The ultimate conclusion is that water governance will prove essential

Water-use efficiency has to be backed up with carefully judged policies and regulatory measures. The benefits of any technical water-use efficiency gains can only be distributed equitably and sustainably with strong institutional purpose and means.

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Annex 1

	Total water withdrawal by sector (year 2017)						Total water withdrawal	Total freshwater withdrawal	Internally Renewable Water Resources (IRWR)	Freshwater withdrawals percent of IWWR
	Agricultural		Municipal		Industrial					
	km³/yr	%	km³/yr	%	km³/yr	%	km³/yr	km³/yr	km³/yr	%
Africa	**194**	**63**	**45**	**14**	**69**	24	**308**	**295**	**3 935**	**7**
Northern Africa	18	82	2	10	2	**29**	22	22	46	48
Sub-Saharan Africa	176	62	42	15	68	41	286	273	3 889	7
Americas	**745**	**58**	**174**	**13**	**370**	21	**1 290**	**1 285**	**19 673**	**7**
Northern America	243	46	73	14	217	9	532	532	6 077	9
Central America and Caribbean	464	66	90	13	149	**5**	704	699	1 209	58
Southern America	38	71	11	20	5	5	54	54	12 387	0.43
Asia	**1 768**	**86**	**184**	**9**	**108**	8	**2 060**	**1 921**	**11 865**	**16**
Western Asia	232	86	27	10	13	2	272	263	485	54
Central Asia	113	87	6	5	11	15	130	99	242	41
South Asia	881	91	67	7	22	8	970	874	1 935	45
East Asia	73	65	22	20	16	**34**	111	113	3 410	3
Southeast Asia	469	81	62	11	46	31	577	572	5 794	10
Europe	**155**	**45**	**73**	**21**	**117**	43	**345**	**330**	**6 590**	**5**
Western and Central Europe	133	49	53	20	84	**13**	270	255	2 177	12
Eastern Europe and Russian Federation	22	30	21	27	32	23	75	75	4 414	2
Oceania	**12**	**73**	**2**	**14**	**2**	8	**16**	**21**	**915**	**2**
Australia and New Zealand	3	62	1	16	1	**16.58**	5	10	819	1
Pacific Islands	9	78	2	14	1	1623	11	11	96	11
WORLD	**2 876**	**71.54**	**478.07**	**11.89**	**666.33**	2 009	**4 020**	**3 851**	**42 979**	**9**
High income	806	2494	225	2553	448	2 009	1 480	1 456	10 322	14
Low & middle income	2069	7185	253	3039	218	2 009	2 540	2 396		7

Source: AQUASTAT

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