Accounting for water resources at catchment scale: understanding the role of ecosystems

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Abstract

South Africa has approximately half of the global average annual rainfall, making water a scarce and limiting resource in terms of economic and social development. Accounting for water stocks and flows and water related ecosystem services is of interest and has been given particular attention in recent years. A range of water-related accounts have been produced over the past two decades, including National Water Accounts based on SEEA-Water (Stats SA 2000, 2004, 2006, 2009, 2010), Accounts for Strategic Water Source Areas[1] (Stats SA 2023), detailed catchment-scale water resource accounts (Clark 2015 and Clark 2019), and experimental ecosystem service accounts for one province that included water supply (Turpie *et al*. 2021). These accounts are intended to provide a range of statistics, indicators and improved information to facilitate better understanding and decision-making with respect to water as a scarce resource and the ecosystems, catchments and landscapes that are important for the quantity and quality of supply of water. As such, the interlinkages between different types of accounts are important.

This paper focuses on water resource accounts. Water resource accounts in South Africa are physical accounts at the catchment scale, quantifying stocks, flows and consumption of water within a defined spatial and temporal domain. They have been compiled for several catchments to date, with a vision to eventually produce these for all catchments in the country, annually. The accounts facilitate exploring linkages between land cover, land use, ecological infrastructure[2] and catchment water resources. This requires some degree of alignment of methods and scope, which is enabled by using: (i) a common basic spatial unit and spatially explicit data, supporting compatibility in reporting areas, and (ii) a common hierarchical land cover classification.

In the water resource accounts, detailed accounts showing the extent of different land cover/use classes and modelled estimates of the hydrological responses of these classes have been compiled for the first time. These accounts additionally include estimates of water resources based on natural land cover for the whole catchment to help in understanding and quantifying the impacts of land cover/use changes. These accounts provide a wealth of information and are intended to complement the National Water Accounts (based on the SEEA-Water framework) at a national and sub-national level.

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[1] **Strategic water source areas (SWSAs)** are natural source areas for water that supply disproportionately large volumes of water per unit area and that are considered of strategic significance for water security from a national planning perspective, either for surface water, groundwater or both (Stats SA 2023). SWSAs are national ecological infrastructure assets that contribute significantly to the overall surface and ground water supply of the country.

[2] **Ecological infrastructure** refers to naturally functioning ecosystems that generate or deliver valuable services and benefits to people and the economy (SANBI, 2016). Water-related ecological infrastructure includes wetlands, rivers, riparian areas and SWSAs, and their associated catchments, which contribute to the production of clean water, flood moderation, prevention of erosion and drought resilience, also supporting resilience to climate change (Stats SA 2023).

This paper will briefly describe the catchment-level water resource accounts being developed in South Africa. It touches on conceptual issues, the modelling approach used and the facilitation of interlinkages with other natural capital accounting domains in South Africa.

1. Introduction

To provide some context to the water resource accounts discussed in this paper, the water resource environment in South Africa is described briefly, followed by some background information about water related accounts produced in South Africa to date.

1.1 The water resource environment in South Africa

Water is a scarce and limiting resource in South Africa in terms of economic and social development. South Africa has an average annual rainfall of 464 mm, approximately half the global average (DWS, 2018). The total annual runoff is approximately 49 000 million m^3/a (DWS, 2018), with approximately half of the country's runoff contributed by just 8% of the land area country (WWF-SA, 2017). Rainfall and runoff also have a high temporal variability, both intra- and inter- annually, and it is anticipated that climate change may also have a significant impact on rainfall and temperature in some parts of the country. As is the case globally, human activity has resulted in the degradation of land and ecosystems, which further impacts the quantity and quality of water resources. South Africa shares rivers and thus water resources with six neighbouring countries (Botswana, Eswatini, Lesotho, Mozambique, Namibia and Zimbabwe).

South Africa has a long history of water monitoring and national water resource assessment studies. Water storage infrastructure in South Africa is highly developed to assist in managing variability in rainfall and runoff, including many large dams and also several large-scale inter-catchment transfers to augment water resources in high demand areas. However, options for further water infrastructure development are becoming less physically and economically feasible, requiring better management of water resources and the existing built infrastructure. There is also growing recognition of the role of ecological infrastructure in supplementing or even serving in place of built infrastructure in catchment water resource management plans. The National Water Act (NWA, 1998) of South Africa (Act 36 of 1998) recognises "*the need for the integrated management of all aspects of water resources*". An integrated approach that recognises that there are hydrological, engineering, ecological, economic, political, social and institutional aspects to water resources management, which need to be considered to ensure sustainable and equitable use. The effective implementation of this integrated water management paradigm will need to be informed by better data.

The formalised quantification of natural resources in the form of natural capital accounts is invaluable in building understanding and in informing land use, environmental and water management and policy decisions. Natural systems are complex and complicated, thus an integrated set of accounts recognising the interactions between accounting domains (e.g. land, ecosystems, water) is required. Water, in particular, is a point of commonality cutting across many accounting domains.

1.2 Background to accounts related to water in South Africa

Given the water resource constraints in South Africa, accounting for water stocks and flows and water related ecosystem services is of interest and has been given particular attention in recent years. A range of water-related accounts have been produced over the past two decades, including National Water Accounts (Stats SA 2000, 2004, 2006, 2009, 2010) based on the System of Environmental-Economic Accounting (SEEA) framework, Accounts for Strategic Water Source Areas (Stats SA 2023), detailed catchment-scale water resource accounts (Clark 2015 and Clark 2019), and experimental ecosystem service accounts for one province that included water supply (Turpie *et al*. 2021). These accounts are intended to provide a range of statistics, indicators and improved information to facilitate better understanding and decision-making with respect to water as a scarce resource and the ecosystems, catchments and landscapes that are important for the quantity and quality of supply of water. As such, the interlinkages between different types of accounts are important.

The National Water Accounts (Stats SA 2000, 2004, 2006, 2009, 2010), compiled by Statistics South Africa (Stats SA) are based on the SEEA-Water framework[3]. These National Water Accounts, include estimates of water use and production by different economic sectors, including agriculture, mining, electricity, commercial and industrial, and domestic. The intention is for Stats SA to work together with the Department of Water and Sanitation (DWS) to publish these accounts on a more regular basis, at a national and Water Management Area (WMA) scale (9 WMAs in South Africa). The SEEA-Water framework (UN, 2012) has a strong economics emphasis. It aims to measure the use of water resources by the economy and the impact of the economy on water resources. SEEA-Water recognises the catchment level water cycle and the landscape hydrological processes that govern this cycle, but is less focussed on the whole catchment water cycle, though this is important for the supply of water to the economy and receipt of return flows from the economy.

In South Africa a set of Strategic Water Source Areas (SWSAs) has been delineated (Figure 1). These SWSAs are defined as "*natural source areas for water that supply disproportionately large volumes of water per unit area and that are considered of strategic significance …*" and are important areas for the country's water security (Stats SA 2023). Using these SWSAs as accounting areas, land accounts and accounts for protected areas in SWSAs were developed and reported for all SWSAs, combined and per SWSA, in the Accounts for SWSAs, 1990 to 2020 (Stats SA 2023). These accounts provide information on land cover and use (an indicator of socio-economic activity) within the SWSAs, which can impact the ecological condition of water-related ecosystems in these areas, thus their ability to provide water, both within and beyond their boundaries. The land accounts for SWSAs are methodologically in line with the *Land and Terrestrial Ecosystem Accounts, 1990 to 2014* (Stats SA 2020) and the accounts of protected areas in SWSAs are methodologically in line with the *Accounts for Protected Areas, 1990 to 2020* (Stats SA 2021).

The experimental ecosystem service accounts developed by Turpie *et al*. (2021), aimed to quantify and value the supply of ecosystem services provided by various terrestrial and aquatic ecosystem assets in the province of KwaZulu-Natal in South Africa. The ecosystem related services evaluated included selected provisioning, cultural and regulating services. The water regulating services evaluated included: flow regulation, flood attenuation and water quality amelioration. These accounts, compiled in physical and monetary terms, based on SEEA Ecosystem Accounting, (EA) were developed as part of the Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES)[4] Project in which South Africa was a pilot country. There are methodological linkages between these accounts, the Land and Terrestrial Ecosystem Accounts (Stats SA 2020) and the Accounts for Protected Areas (Stats SA 2021).

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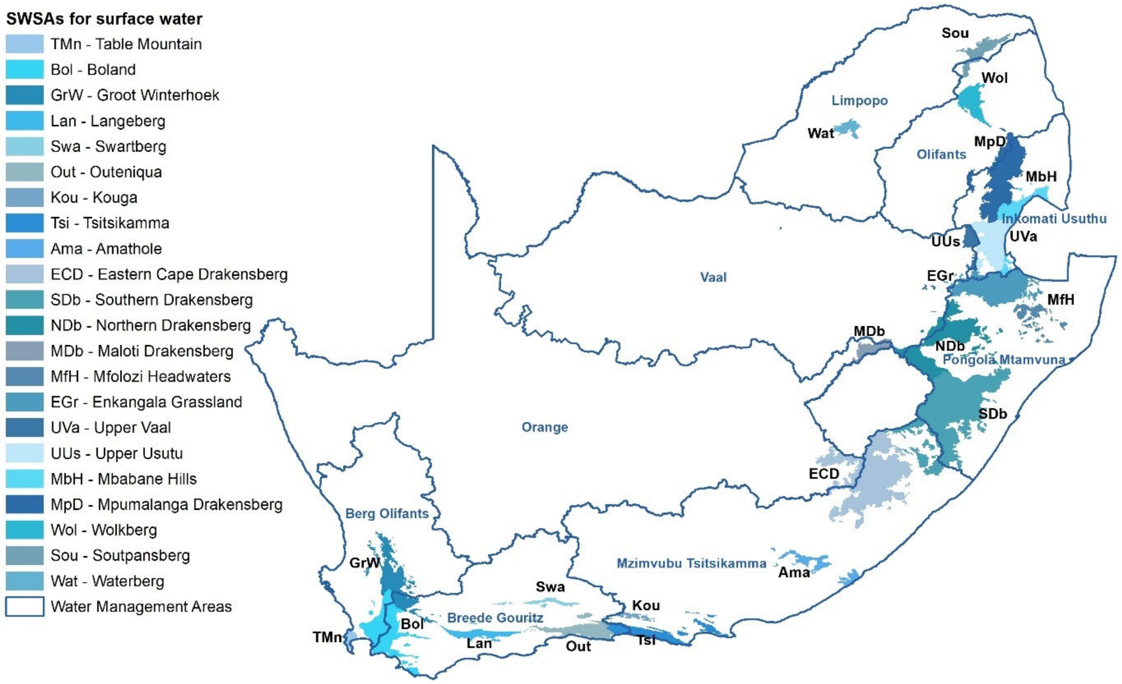
[3] The National Water Accounts were last published by Statistics South Africa in 2010, but more recent accounts and a methodology for producing these were developed by Maila *et al*. (2018) through a project funded by the Water Research Commission (WRC) of South Africa. Stats SA intends to publish further National Water Accounts from next year.

[4] The NCAVES project was funded by the European Union (EU), and led globally by the United Nations Statistics Division (UNSD) and United Nations Environment Programme (UNEP), and led in South Africa by Stats SA and the South African National Biodiversity Institute (SANBI) in partnership with the Department of Forestry, Fisheries and Environment (DFFE).

Figure 1. Spatial distribution of SWSAs for surface water in South Africa and the country's nine WMAs. National Water Accounts are done for the whole country using SEEA Water, disaggregated to the WMAs. Accounts for SWSAs were done as SEEA Ecosystem Account thematic accounts using the SWSAs as the accounting area.



This paper focuses on water resource accounts. Water resource accounts in South Africa are physical accounts at the catchment scale, quantifying stocks, flows and consumption of water within a defined spatial and temporal domain. These accounts are referred to as "water resource accounts" to differentiate them from the National Water Accounts, based on SEEA-Water. The water resource accounts aim to provide modelled estimates of a complete catchment water balance, with a strong emphasis on land cover and land use, at a range of catchment scales. The water resource accounts are intended, primarily, to support catchment level water management decisions. A methodology has been developed for producing these water resource accounts using national datasets that are readily available in South Africa. Water resource accounts have been compiled for several case study catchments in South Africa to: (i) test the methodology proposed for compiling these accounts, and (ii) provide an opportunity for stakeholders and natural capital accounting practitioners to engage with and comment on these accounts. The next section describes these accounts in more detail, giving examples of water resource account tables and indicators.

2. Water Resource Accounts

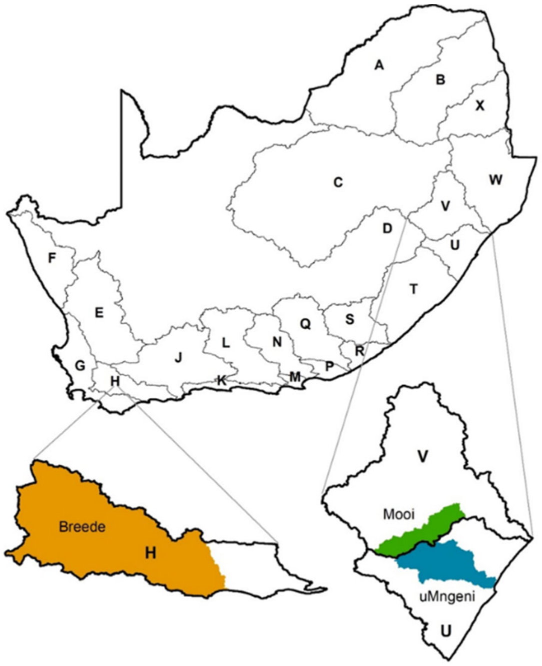
This section provides a brief summary of the background to the development of the water resource accounts and presents indicative results sufficient for the discussion of key issues in the Discussion section.

2.1 Background to the development of the water resource accounts

Initially led by a university research unit (the CWRR at UKZN), with Water Research Commission (WRC) funding, the methodology for producing the water resource accounts was based on the Water Accounting Plus (WA+) framework (Karimi et al. 2013). Through a Global Environment Facility (GEF)-

funded project, called the Ecological Infrastructure for Water Security (EI4WS) Project[5], specific methodological linkages with land cover, using the same land cover/use classes as in the Land and Terrestrial Ecosystem Accounts, were explored (see Box 1 in Section 2.2).

Figure 2. Location of selected catchments, in relation to the primary catchments[6] (named A to X) in South Africa.



The water resource accounts for the EI4WS Project focus on selected catchments in the two demonstration catchment areas (Figure 2) of the EI4WS Project, namely the Berg-Breede (serving the City of Cape Town) in the Western Cape province and the Greater uMngeni (serving eThekwini and uMgungundlovu) in KwaZulu-Natal.

Modelled streamflow was verified using measured streamflow, where available. The draft accounts were validated with key stakeholders in each of the demonstration catchment areas.

The accounts are being finalised for release by Stats SA and therefore the actual results cannot be presented here[7]. **This paper shows indicative results for the purposes of a discussion but it should be noted that these are not the final results of the water resource accounts.**

2.2 Indicative results of water resource account

The water resource account tables and related indicators described in this section show the type of information about catchment water resources that is contained in these accounts. The account tables aim to: (i) represent the whole catchment water balance (though in varying degrees of detail), (ii) provide time series of water balances to help in understanding variability and to provide context for individual accounting periods, (iii) show the impact of land cover/use (at an aggregated level using four broad land cover/use classes). Values can be shown in the account tables as volumes or normalised as depths. Volumes are useful for water supply type estimates. However, showing values as depths is also useful as: (i) rainfall and evaporation are usually referred to as depths in mm, thus, providing other quantities as depths helps with understanding the catchment water balance quantities, and (ii) normalisation as depths enables water resources in catchments of different sizes

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[5] The EI4WS Project is implemented by the Development Bank of Southern Africa and executed by SANBI in partnership with the Department of Forestry, Fisheries and the Environment, the Department of Water and Sanitation (DWS) and many other partners. It is a seven-year project, initiated in February 2018, to unlock development finance to secure ecological infrastructure for water security in two systems of catchments that are critical to water supply to two major urban centres.

[6] South Africa consists of 22 primary catchments, defined by the Department of Water and Sanitation, which in turn are sub-divided into nested secondary, tertiary and quaternary sub-catchments. Many quaternary catchments are several hundred square kilometres in size, within which topography and climate may vary greatly. The hydrological modelling has thus far been done for sub-quaternary catchments, to reduce variability in topography and climate, but quaternary catchments are the smallest accounting areas used for reporting, and the water resource accounts can be aggregated all the way up to primary catchment and even national level.

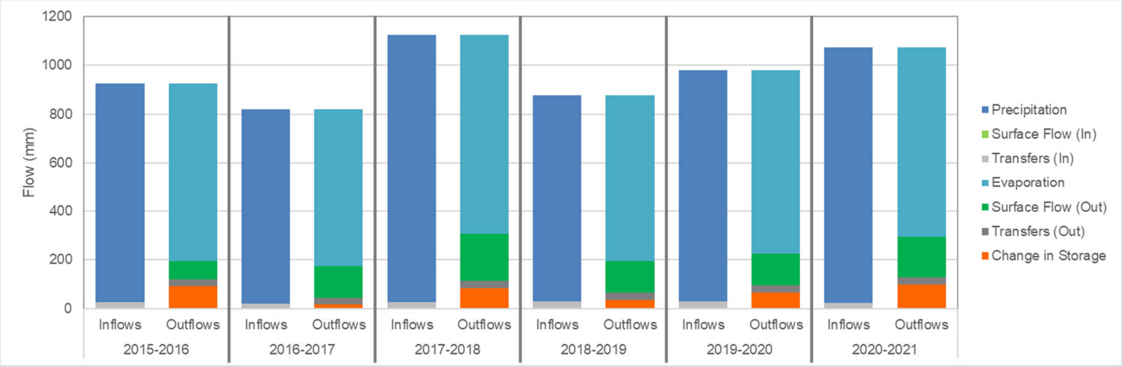
[7] With the publication of statistical releases, Stats SA is guided by their Publications and Data Access Policy and the Media policy for Stats SA, which in turn are based on the Statistics Act and the UN Fundamental Principles of Official Statistics. Stats SA adheres to equal access to statistics releases, where all users will have equal access to such statistics releases at the same time. It is standard practise for Stats SA to not share any content of releases until the pre-scheduled embargo date and time.

to be compared. The water resource accounts are currently annual accounts, compiled for hydrological years running from October to September. However, the hydrological modelling is done at a daily time step (to better represent hydrological processes) and model output is aggregated to monthly values which could be aggregated to other accounting time periods. In these examples only four high-level land cover/use classes are represented, though many more land cover use subclasses are used in the hydrological modelling.

Due to the high level of temporal variability in climate and related variability in catchment water resources, water asset accounts are of limited use and thus the water resource accounts are primarily intended to be flow accounts. In addition, large stocks such as groundwater stores and even soil water stores are difficult to quantify, thus the water resource accounts show changes in stocks, but not the start and end stock for a time period.

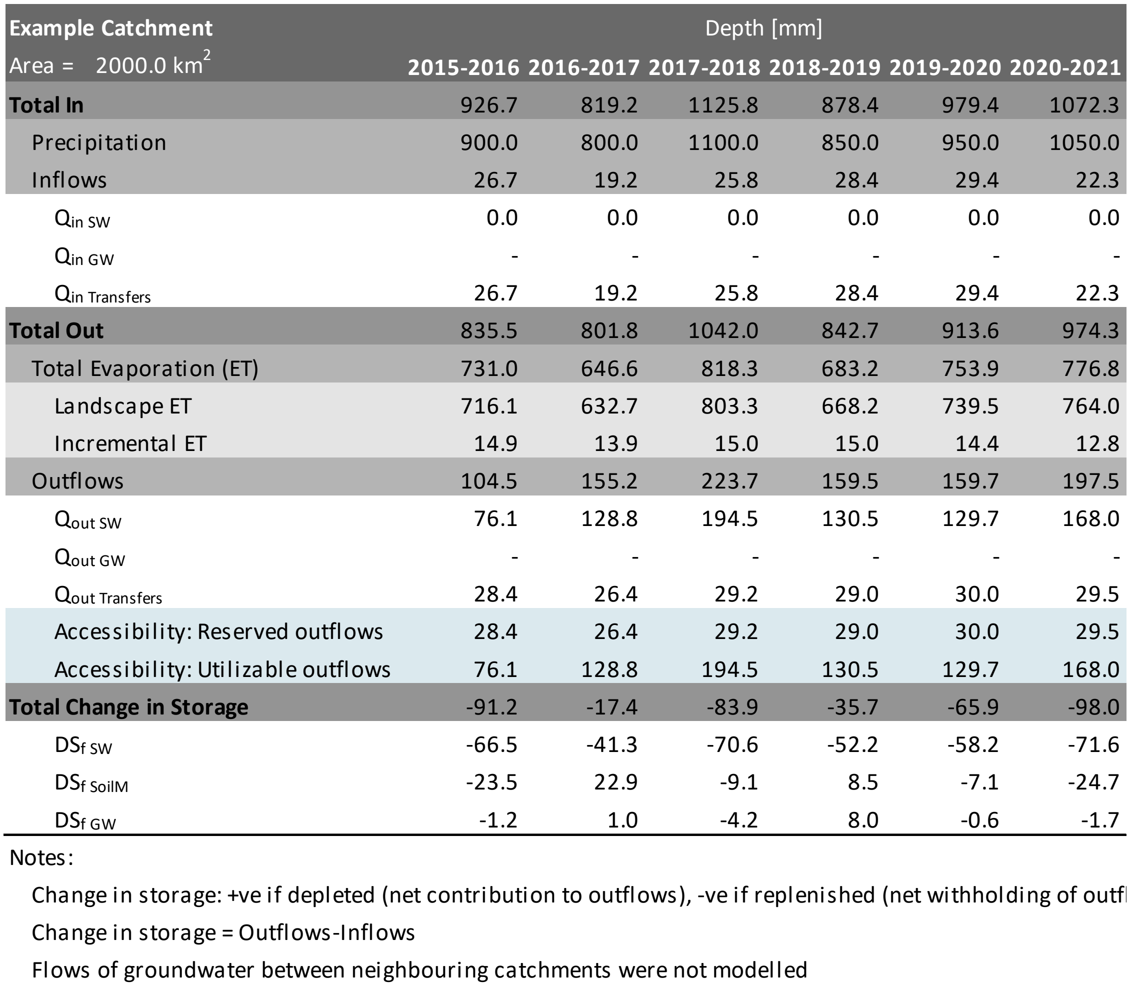
An overview of the water resources in the form of the main catchment inflows and outflows, for several individual accounting time periods, is shown in the graph in Figure 3. The left-hand bar for each time period shows the inflows, and the right-hand bar shows the outflows. Precipitation and total evaporation are typically the predominant processes affecting catchment water resources. Thus, only a relatively small portion of rainfall becomes so called ‘blue water’ in rivers and dams. Additionally, catchment water resources may be augmented by inflows from upstream catchments and inter-catchment transfers (this is the case in the example shown below). A catchment may also serve as a water source to neighbouring catchments through river outflows to downstream catchments and inter-catchment transfers. Natural water stores such as the soil profile and groundwater store, together with engineered water infrastructure in the form of dams, may be replenished or drawn down during an accounting time period. The changes in storage of water in the catchment (shown in orange) move between the left-hand bar (indicating drawdown) and the right-hand bar (indicating replenishment of storage - the case in all years in the example shown below).

Figure 3. Indicative results for a catchment over six accounting periods displayed as a time series of catchment inflows and outflows (normalised as depths)



The water resource base table shown in Table 1, provides a similar overview of the catchment water balance, but in table form and with a little more detail regarding total evaporation , accessibility of outflows and changes in storage. This table is similar to the SEEA-Water asset account table. Landscape evaporation is the evaporation of water (provided in the form of precipitation) from the landscape. Incremental evaporation is evaporation of water supplied from rivers, dams and groundwater for irrigation and urban use. In the example shown below, all reserved flows are for export to urban areas in neighbouring catchments. In other catchments, reserved flows might form part of surface water outflows for irrigation or to meet environmental flow requirements in downstream catchments. In the example shown below, surface water storage in dams is replenished in all of the 6 years, while groundwater storage is reduced in the two drier years. Showing a time series of water balances for a few consecutive years enables comparison between drier and wetter years.

Table 1. Water resource base table with indicative results for a catchment for six accounting periods (normalised as depths)



Example Catchment Area = 2000.0 km^2	Depth [mm] **2015-2016**	 **2016-2017**	 **2017-2018**	 **2018-2019**	 **2019-2020**	 **2020-2021**
Total In	926.7	819.2	1125.8	878.4	979.4	1072.3
Precipitation	900.0	800.0	1100.0	850.0	950.0	1050.0
Inflows	26.7	19.2	25.8	28.4	29.4	22.3
$Q_{in\ SW}$	0.0	0.0	0.0	0.0	0.0	0.0
$Q_{in\ GW}$	-	-	-	-	-	-
$Q_{in\ Transfers}$	26.7	19.2	25.8	28.4	29.4	22.3
Total Out	835.5	801.8	1042.0	842.7	913.6	974.3
Total Evaporation (ET)	731.0	646.6	818.3	683.2	753.9	776.8
Landscape ET	716.1	632.7	803.3	668.2	739.5	764.0
Incremental ET	14.9	13.9	15.0	15.0	14.4	12.8
Outflows	104.5	155.2	223.7	159.5	159.7	197.5
$Q_{out\ SW}$	76.1	128.8	194.5	130.5	129.7	168.0
$Q_{out\ GW}$	-	-	-	-	-	-
$Q_{out\ Transfers}$	28.4	26.4	29.2	29.0	30.0	29.5
Accessibility: Reserved outflows	28.4	26.4	29.2	29.0	30.0	29.5
Accessibility: Utilizable outflows	76.1	128.8	194.5	130.5	129.7	168.0
Total Change in Storage	-91.2	-17.4	-83.9	-35.7	-65.9	-98.0
$DS_{f\ SW}$	-66.5	-41.3	-70.6	-52.2	-58.2	-71.6
$DS_{f\ SoilM}$	-23.5	22.9	-9.1	8.5	-7.1	-24.7
$DS_{f\ GW}$	-1.2	1.0	-4.2	8.0	-0.6	-1.7

Notes:

Change in storage: +ve if depleted (net contribution to outflows), -ve if replenished (net withholding of outfl

Change in storage = Outflows-Inflows

Flows of groundwater between neighbouring catchments were not modelled

The more detailed water resource table shown in Table 3, includes a similar catchment water balance on the left-hand side, though with more detail of the types of evaporation and also internal catchment flows such as surface runoff, infiltration and baseflow. More importantly this table includes a water balance for four broad land cover classes (Box 1). The example shown in Table 3 represents a highly developed catchment with relatively large proportions of cultivation, built-up areas (cities) and dams for water supply. To provide an indication of overall land cover and land use change, the model was additionally configured such that the whole catchment had natural land cover (as a reference), and the catchment water balance for this reference natural land cover is shown on the right-hand side of the table. The percentage difference between the water balance components under actual and reference natural land cover is shown in the rightmost column. This table shows water quantities for a single accounting period. This additional land/cover use detail helps in understanding the impact of each of the four broad land cover classes on water resources. The water quantities are shown as volumes, depths and percentages. Percentages for catchment totals are summed vertically within the columns, percentages for land cover classes are summed horizontally within the rows. Summing the percentages horizontally for the land cover classes enables the impact of a class, relative to it's proportion of the total catchment area to be determined. For the example shown in Table 3, precipitation is roughly proportional to the area of the four broad land cover classes, whereas in the case of built-up areas there is a higher proportion of surface runoff and a lower proportion of total evaporation.

Box 1. Hierarchy of land cover classes

The water resource accounts have a strong land cover and land use focus to represent actual land cover/use, assess the impact of land use change and to promote integration with other natural capital accounts such as land accounts and ecosystem accounts with which there are strong synergies. Within each catchment a number of hydrological response units are defined based on land cover classes with different hydrological responses. The land cover classes used in the hydrological modelling are determined using a national land cover dataset (with 73 classes), together with the National Vegetation Map (SANBI, 2012) of natural vegetations types and a dataset of dam spatial extents (when full). Climate and soil characteristics are averaged across each catchment.

Table 2. The common hierarchical four-tier land cover classification used to produce accounts

Broad land cover classes	**Main land cover classes**	**Detailed land cover classes**	**National land cover classes**
Tier 1: 4 classes	*Tier 2: 8 classes*	Tier 3: 19 classes	Tier 4: 73 classes
Natural or semi-natural	Natural or semi-natural	Natural or semi-natural	21 land cover classes
Cultivated	Commercial field crops	Commercial field crops (dryland)	2 land cover classes
		Commercial field crops (non-pivot irrigated)	1 land cover class
		Commercial pivot crops (pivot irrigated)	1 land cover class
		Sugarcane	3 land cover classes
	Subsistence crops	Subsistence crops	1 land cover class
	Orchards and vines	Orchards	1 land cover class
		Vines	1 land cover class
	Timber plantations	Timber plantations	3 land cover classes
Built-up	Urban	Residential formal	5 land cover classes
		Residential informal	4 land cover classes
		Smallholdings	4 land cover classes
		Village	2 land cover classes
		Recreational fields	4 land cover classes
		Commercial	1 land cover class
		Industrial and transport	2 land cover classes
	Mines	Mines	5 land cover classes
Waterbodies	Waterbodies	Natural waterbodies	10 land cover classes
		Artificial waterbodies	2 land cover classes

Table 3. Detailed water resource account table with indicative results for a catchment for a single accounting period, the 2020-2021 year. The table is detailed in that is presents variables for the catchment as a whole (total) and for each of the four broad land cover classes in the catchment. It also provides reference land cover values (as if the whole catchment had natural or semi-natural land cover) and the difference between the reference and the actual land cover values (total).

Example Catchment		Total			Natural or semi-natural			Cultivated			Built-up			Waterbodies			Reference		Difference
Area		[km^2]	%		[km^2]	%		[km^2]	%		[km^2]	%		[km^2]	%		[km^2]	%	
		2000.0	100.0		908.2	45.4		669.3	33.5		357.6	17.9		64.9	3.2		2000.0	100.0	
Water resource details	Volume	Depth	%	Volume	Depth	%	Volume	Depth	%	Volume	Depth	%	Volume	Depth	%	Volume	Depth	%	%
2020-2021	[Mm^3]	[mm]		[Mm^3]	[mm]		[Mm^3]	[mm]		[Mm^3]	[mm]		[Mm^3]	[mm]		[Mm^3]	[mm]		
Total In	2144.6	1072.3														2100.0	1050.0		2.1
Precipitation	2100.0	1050.0	97.9	932.6	466.3	44.4	723.9	362.0	34.5	378.1	189.1	18.0	65.3	32.7	3.1	2100.0	1050.0	100.0	0.0
Inflows	44.6	22.3	2.1													0.0	0.0		
$Q_{\text{in SW}}$	0.0	0.0	0.0													0.0	0.0	0.0	0.0
$Q_{\text{in GW}}$	-	-	-													-	-	-	-
$Q_{\text{in Transfers}}$	44.6	22.3	2.1													0.0	0.0	0.0	0.0
Total Out	1948.7	974.3														2041.5	1020.7		-4.5
Total Evaporation (ET)	1553.6	776.8	79.7	761.6	380.8	49.0	596.0	298.0	38.4	146.4	73.2	9.4	49.5	24.8	3.2	1685.5	842.7	82.6	-7.8
Landscape ET	1528.0	764.0	98.3	761.6	380.8	49.8	593.4	296.7	38.8	123.4	61.7	8.1	49.5	24.8	3.2	1685.5	842.7	100.0	-9.3
Incremental ET	25.7	12.8	1.7	0.0	0.0	0.0	2.6	1.3	10.2	23.0	11.5	89.8	0.0	0.0	0.0	-	-	-	-
Interception ET	352.0	176.0	22.7	201.9	100.9	57.4	117.3	58.6	33.3	30.8	15.4	8.8	2.0	1.0	0.6	460.6	230.3	27.3	-23.6
Transpiration ET	761.9	381.0	49.0	330.8	165.4	43.4	368.0	184.0	48.3	57.1	28.6	7.5	6.0	3.0	0.8	690.4	345.2	41.0	10.4
Soil Water ET	390.7	195.3	25.1	228.9	114.4	58.6	110.1	55.0	28.2	49.4	24.7	12.7	2.3	1.1	0.6	529.6	264.8	31.4	-26.2
Open Water ET	49.0	24.5	3.2	0.0	0.0	0.0	0.7	0.3	1.4	9.0	4.5	18.4	39.3	19.7	80.2	4.8	2.4	0.3	919.9
Outflows	395.1	197.5	20.3													356.0	178.0	17.4	11.0
$Q_{\text{out SW}}$	336.0	168.0	17.2													356.0	178.0	18.3	-5.6
$Q_{\text{out GW}}$	-	-	-													-	-	-	-
$Q_{\text{out Transfers}}$	59.0	29.5	3.0													0.0	0.0	0.0	0.0
Total Change In Storage	-195.9	-98.0		-30.7	-15.4	15.7	-18.2	-9.1	9.3	-147.7	-73.8	75.4	0.7	0.3	-0.3	-58.5	-29.3		
$DS_{\text{f SW}}$	-143.3	-71.6	73.1	-1.3	-0.7	0.7	-0.9	-0.4	0.4	-142.0	-71.0	72.5	1.0	0.5	-0.5	-3.1	-1.5	5.2	0.0
$DS_{\text{f SoilM}}$	-49.3	-24.7	25.2	-27.5	-13.7	14.0	-17.6	-8.8	9.0	-3.9	-1.9	2.0	-0.3	-0.2	0.2	-55.6	-27.8	95.0	0.0
$DS_{\text{f GW}}$	-3.3	-1.7	1.7	-1.9	-0.9	1.0	0.3	0.2	-0.2	-1.7	-0.9	0.9	0.0	0.0	0.0	0.1	0.1	-0.2	-2492.7
Internal Flows	0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		
Interception	354.5	177.2		203.2	101.6	57.3	118.1	59.1	33.3	31.1	15.6	8.8	2.0	1.0	0.6	463.5	231.8		-23.5
Surface Runoff	222.1	111.1		78.0	39.0	35.1	43.5	21.7	19.6	77.2	38.6	34.7	23.4	11.7	10.6	250.5	125.3		-11.3
Infiltration	1363.5	681.8		651.3	325.7	47.8	565.2	282.6	41.5	144.5	72.3	10.6	2.4	1.2	0.2	1385.1	692.5		-1.6
Pot. GW Recharge	167.7	83.9		64.1	32.0	38.2	69.5	34.8	41.5	34.1	17.0	20.3	-	-	-	117.1	58.6		43.2
Baseflow	168.8	84.4		62.0	31.0	36.8	65.9	32.9	39.0	38.7	19.3	22.9	2.2	1.1	1.3	117.2	58.6		44.0
Irrigation	2.9	1.5		0.0	0.0		2.9	1.5	100.0	-	-	-	0.0	0.0		0.0	0.0		

Notes:

Change in storage: +ve if depleted (net contribution to outflows), -ve if replenished (net withholding of outflows)

Change in storage = Outflows-Inflows

Groundwater recharge was not specifically modelled: downward percolation of water out of the root zone is reported here as potential groundwater recharge

Flows of groundwater between neighbouring catchments were not modelled

The water withdrawals, consumption and returns table, shown in Table 4, provides an overview of managed water flows in a catchment. This table is similar to the SEEA-Water physical supply and use tables. This table shows: (i) the total water demand, withdrawals and deficit, (ii) the quantities of water abstracted from different water source types, (iii) how much is abstracted by the Cultivated and Built-up land cover/use classes, (iv) the consumption and return flows for these classes, and (v) the quantities of water returned to the different water source types. In the example shown in Table 4, withdrawals to supply urban water requirements are substantially more than withdrawals for irrigation. Showing a time series of flows for a few consecutive years enables comparison between drier and wetter years. For the information in this sheet to be useful, accurate measurements or reliable modelled estimates of water demand, withdrawals, consumption and return flows at a catchment scale are required.

Table 4. Water withdrawal, consumption and returns table with indicative results for a catchment for three accounting periods (normalised as depths)

Example Catchment	Depth [mm]					
Area = 2000.0 km^2	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
Total Demand	30.9	28.6	30.8	31.0	30.3	28.1
Total Withdrawal	30.5	28.3	30.6	30.3	30.0	28.0
Cultivated	2.7	2.6	3.1	3.0	2.1	1.8
Built-up	27.9	25.6	27.5	27.3	27.9	26.2
Total Consumed	12.2	11.4	12.3	12.3	11.8	10.6
Cultivated	1.6	1.7	2.0	2.0	1.3	1.0
Built-up	10.6	9.7	10.3	10.3	10.6	9.6
Total Returned	15.1	13.9	15.1	14.8	15.1	14.6
Cultivated	-	-	-	-	-	-
Built-up	15.1	13.9	15.1	14.8	15.1	14.6
Deficit	0.3	0.3	0.2	0.7	0.3	0.1

Notes:

Deficits in supply may, in part, be due to assumptions made regarding water sources

Indicators are important for summarising information from the account tables, indicating the status of catchment water resources, comparing water resource availability with water demand, or distinguishing between water resources ‘generated’ internally within a catchment (as a result of precipitation) and the water resources entering a catchment from upstream catchments or via inter-catchment transfers (indicating dependence). Hydrological indicators relating evaporation, surface runoff and groundwater recharge to precipitation, describe the partitioning of rainfall via largely natural hydrological processes.

Some indicators drawn from water resource accounts are listed in Table 4. Several of these are the same as indicators that can be drawn from SEEA-Water accounts. It should be noted that the indicators of water resource availability relate to inflows and outflows occurring within an accounting time period and thus do not take into consideration storage (accumulated in previous accounting time periods) available in the catchment, in dams and the groundwater store, that can be used to mitigate the variability in water resources from one accounting time period to another.

Table 5. Suggested indicators that can be calculated from the water resource accounts

Indicator	**Equation**
Internal water resources ($WR_{Internal}$) The amount of water made available internally through endogenous precipitation within a catchment.	$Surface\ Runoff + Baseflow + Groundwater\ Recharge$
External water resources ($WR_{External}$) The amount of water contributed from outside the catchment via surface water and groundwater inflows and inter-catchment transfers.	$Q_{in\ SW} + Q_{in\ GW} + Q_{in\ Transfers}$
Total water resources (WR_{Total}) The amount of water that would be available for use in a catchment and to provide reserved outflows.	$WR_{Internal} + WR_{External}$
Net water resources (WR_{Net}) The amount of water that would be available for use in a catchment (after providing for reserved outflows.	$WR_{Total} - Outflows_{Reserved}$
Water resources dependency ratio ($WR_{Dependency}$) The reliance of a catchment on water resources contributed from outside the catchment.	$\frac{WR_{External}}{WR_{Total}}$
Reserved outflow ratio The fraction of total water resources that are reserved for "export" to other catchments.	$\frac{Outflows_{Reserved}}{WR_{Total}}$
Exploitation Index The magnitude of gross water withdrawals and reserved outflows relative to available water resources, indicating water stress.	$\frac{Withdrawals_{Total} + Outflows_{Reserved}}{WR_{Total}}$
Internal Exploitation Index The magnitude of gross water withdrawals relative to available internal water resources after reserved outflows have been deducted.	$\frac{Withdrawals_{Total}}{WR_{Net}}$
Consumption Index The magnitude of water withdrawals actually consumed (depleted) relative to available water resources.	$\frac{Consumed_{Total}}{WR_{Total}}$
Per capita total water resources Ratio between total water resources and population size.	$\frac{WR_{Total}}{Population}$
Per capita net water resources Ratio between net water resources and population size.	$\frac{WR_{Net}}{Population}$
Per capita internal water resources Ratio between internal water resources and population size.	$\frac{WR_{Internal}}{Population}$

3. Discussion

This section discusses interlinkages with other accounts and some of the interesting and challenging aspects of water resource accounts.

3.1 Interlinkages of water resource accounts with other natural capital accounts

Interlinkages of water resource accounts with other natural capital accounts requires, at a technical level, some degree of alignment of methods and scope between the relevant natural capital accounts. This alignment was enabled through two elements.

Firstly, through the use of a common basic spatial unit used for all ecosystem accounts, land accounts and water resource accounts in South Africa. SEEA Ecosystem Accounting (UN, 2021) makes provision for the use basic spatial units (BSUs) in compiling accounts, though the BSUs themselves are not accounting areas. A national set of BSUs in the form a 1 ha grid (100 m x 100 m) has been developed for South Africa. The BSUs are intended to provide a "*consistent spatial framework for integrating* *data*" (Stats SA, 2020) between various NCA domains. The starting point for configuring a hydrological model for the purpose of compiling water resource accounts is to effectively compile land accounts, from which land cover/use based hydrological response units (HRUs) are determined. The 1 ha BSUs were applied in deriving the land cover/use HRUs in each catchment from the 20 m spatial resolution national land cover dataset available for South Africa. There is a trade-off here, where use of the land cover data at BSU resolution enables compatibility, but may mean that some land cover features that are typically small in area (e.g. farm dams) or narrow (rivers) may be underrepresented. It is important to note that the hydrological modelling is not currently done at the resolution of the BSUs.

The second element that supported interlinkages between the accounts was the use of a common hierarchical land cover classification used both in land accounts and in water resource accounts (refer to Box 1). The strong land cover and land use representation within the water resource accounts, together with the fact that they are compiled for relatively fine geophysical spatial accounting areas, means that the water resource accounts were well suited to exploring interlinkages between water resources and other natural capital accounting domains representing land cover, land use and ecosystems. The inclusion of information on land cover is also important because it links what happens in the terrestrial parts of catchment landscapes to impacts on water resources in rivers and dams in a manner that enables exploration of different scenarios of land management on water resource management. This is important not least because land cover change is resulting in greater impacts on water security than climate change in certain parts of the country.

A factor that limits linkages with other accounts is the accounting area. Although the use of catchments as accounting areas make sense for water resource accounts and for users such as Catchment Management Agencies, catchments are often not well aligned spatially with economic and administrative accounting areas, such as provinces and municipalities. This can create a disconnect with other natural capital accounts, such as ecosystem accounts based on SEEA, and also for their application in land-use planning and decision-making, which is typically carried out by provincial and municipal authorities.

3.2 Modelling and data aspects of producing the water resource accounts

A hydrological modelling approach is used as many components of the hydrological cycle at catchment level are either: (i) difficult to measure, or (ii) are not measured across the whole country at a suitably detailed spatial resolution. A deterministic simulation type model based on physical and empirical equations and input variables was selected for this purpose. Such a model can make provision for non-stationarity (such as climate change and changes in land cover over time) and avoids the need for calibration, thus making it suitable for application in ungauged catchments (i.e. catchments with no flow gauge measurements). This modelling approach, in addition to its use in quantifying existing water resources, as reported in the accounts, enables what-if scenarios to be evaluated for use in guiding management decisions. The ACRU hydrological model (Schulze, 1995; Smithers and Schulze, 1995), developed in South Africa, has been used for the water resource accounts developed to date.

The hydrological modelling on which the water resource accounts are based is data intensive, requiring data related to climate, land cover/use, soil properties, dams, river networks, inter-catchment transfers, irrigation and urban water use. National datasets were used in the water resource accounts but also have their limitations and challenges. Advances in remote sensing technologies show promise for future application, however, these should be combined with in situ data and/or national expert input[8]. Validation workshops with regional experts (i.e. even within one country) highlighted the importance of involvement of local or regional experts in validation and interpretation.

Compiling the water resource accounts has emphasized the availability of many useful datasets describing bio- and geophysical characteristics of South Africa. However, it has also highlighted the need for: (i) further investment in monitoring, reporting and dataset development, (ii) accessibility of datasets, between government institutions and by natural capital accounting practitioners, and (iii) improving the usability of datasets, through centralization of data repositories and application of data quality controls. Accurate spatial estimates of climate variables and anthropogenic water use are two key data challenges to be addressed going forward.

The water resource accounts do not include water quality, which we recognise is an important aspect of water resources. Water quality accounts at a fine scale for the whole country would not be easy as (i) measurements are typically made at points of interest, and (ii) modelling water quality would require detailed time series data on sources and concentrations of point source pollution, and many assumptions about non-point source pollution.

3.3 Indicators and presentation of results from the accounts

The hydrological modelling for the water resource accounts provided a huge amount of information, with varying degrees of certainty, for a large number of spatial accounting areas and accounting time periods, and even in different units of measurement (which are meaningful in different contexts of water resource management). The structuring and formatting of account tables to present this wealth of information, in an appropriate level of detail and in a manner that is useful and easy to understand for a range of potential users of this information, was not simple. Validation workshops with potential users of the information for these accounts was useful for identifying useful indicators and ways of presenting results, including the level of detail.

3.4 The relationship with SEEA-Water accounts

SEEA-Water recognises the catchment level water cycle and the associated hydrological processes, which it refers to as the "*inland water resource system*". However, many landscape-level water flows within catchments do not fit neatly with the economic sectors that underpin the SEEA framework for economic accounting. In addition, the SEEA-Water accounts, with their intentional link between physical measures of water stocks and flows and economic measures relating to water, are typically compiled for administrative accounting areas, which are not often well aligned spatially with natural accounting areas such as catchments.

Economic sector level data is also not typically available at a sufficient level of spatial detail that it can easily be applied to catchment accounting areas. Thus, there is a disconnect between natural accounting areas (i.e. catchments) and economic accounting areas (i.e. countries, provinces, municipalities).

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[8] Experience has shown that global datasets need to be used with caution as, in addition to the often coarse spatial and temporal resolution of these datasets, they can result in large biases in the estimates, especially when applied to relatively small accounting areas, due to inaccuracies in measurement, the assumptions made, the estimates of parameters used in modelled datasets and the often poor availability of local data for use in calibration of modelled datasets.

The water resource accounts were originally based on the Water Accounting Plus (WA+) framework (Karimi et al., 2013) which has a catchment scale land and water management focus. The water resource accounts have evolved based on stakeholder feedback to fill a position somewhere between the WA+ framework and the SEEA-Water accounts. These water resource accounts are intended to be complementary to the National Water Accounts based on SEEA-Water. The water resource accounts could potentially provide finer spatial scale estimates of water supply from the environment for use in the SEEA-Water physical accounts. If compiled for suitably fine scale accounting areas SEEA-Water physical accounts could potentially provide estimates of water use for application in the water resource accounts. Detailed information on water demand, supply, consumption and return flows by economic sector is required for both the National Water accounts and the water resource accounts.

4. Concluding Remarks

The water resource accounts described in the paper represent a different but complementary view point to the National Water Accounts based on SEEA-Water. The water resource accounts are spatially explicit, provide a more detailed and holistic catchment level view of water resources than the National Water Accounts, and are thus better suited to supporting water management decision making at a range of scales, rather than policy level decisions. Water resource accounts can be compiled for nested catchment scales, from quaternary catchments to primary catchments, and thus can enable reporting at different levels for different purposes (e.g. local catchment management vs national strategic planning for water). Climate and water availability can vary substantially both spatially and temporally, thus the smaller accounting areas can help in providing greater understanding of water availability and use in water rich vs water poor parts of the country.

The vision is that eventually annual water resource accounts will be compiled for the whole country, every year, at a range of catchment scales (quaternary catchments up to primary catchments). Realising this vision will require (i) high level discussion regarding data access and institutional ownership of the accounts and their production, and (ii) capacity building among stakeholders regarding the potential value and application of the information in the accounts.

5. Questions for Consideration by the London Group

- The SEEA Water accounts are typically compiled for relatively large administrative or economic accounting areas, such as countries or provinces. However, catchments generally make better sense as accounting areas for water resources and there is commonly a mismatch between natural and administrative boundaries between and within countries.
    - How do other countries deal with the mismatch between catchments and administrative boundaries for water management and water accounting?
    - What recommendations do you have for managing these mismatches to enable the water resource accounts to best complement SEEA-Water and other natural capital accounts based on SEEA?
- A modelling approach was adopted for compiling the water resource accounts. This approach was selected to counter the problem of the lack of measured data describing water resources at a suitable level of detail for water resources management. However, deterministic hydrological models, still require a substantial amount of input data. This input data may be available in varying degrees of accuracy and the model itself may over-simplify the representation of physical hydrological processes.
    - Is a modelling approach acceptable, considering data constraints and the implications when making interlinkages with other natural capital accounts?

    - What level of detail and accuracy is appropriate to provide modelled water resource accounts for a whole country without excessive effort?
- What interlinkages can be made with other natural capital accounts to provide better information for management of water resources and landscapes, and also for the policies that guide management of resources?

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7. References

Bailey, AK and Pitman, WV. 2015. Water resources of South Africa 2012 study (WR2012). WRC Report K5/2143/1. Water Research Commission (WRC), Pretoria, South Africa.

Clark, DJ. 2015. Development and Assessment of an Integrated Water Resources Accounting Methodology for South Africa. WRC Report 2205/1/15. Water Research Commission (WRC), Pretoria, South Africa.

Clark, DJ. 2019. Development and Assessment of an Integrated Water Resources Accounting Methodology for South Africa: Phase 2. WRC Report 2512/1/19. Water Research Commission (WRC), Pretoria, South Africa.

Department of Water and Sanitation (DWS). 2018. National Water and Sanitation Master Plan - Volume 1: Call To Action. Department of Water and Sanitation, Pretoria, South Africa.

Karimi, P, Bastiaanssen, WGM and Molden, D. 2013. Water Accounting Plus (WA+) - a water accounting procedure for complex river basins based on satellite measurements. Hydrology and Earth System Sciences, 17 (7): 2459-2472.

Le Maitre, DC, Seyler, H, Holland, M, Smith-Adao, L, Nel, JL, Maherry, A and Witthüser, K. 2018. Identification, Delineation and Importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for Surface Water and Groundwater. Report No. TT 743/1/18, Water Research Commission, Pretoria.

Maila, D, Crafford, J, Mathebula, V, Naidoo, N and Visser, W. 2018. National Water Accounts For South Africa: Systems, Methods and Initial Results. WRC Report TT 774/18. Water Research Commission (WRC), Pretoria, South Africa.

Schulze, RE. 1995. Hydrology and Agrohydrology: A Text to Accompany the ACRU 3.00 Agrohydrological Modelling System. Water Research Commission, Pretoria, South Africa.

Smithers, JC and Schulze, RE (eds.). 1995. ACRU Agrohydrological Modelling System : User Manual Version 3.00. WRC Report No. TT70/95. Water Research Commission, Pretoria, South Africa.

South African National Biodiversity Institute (SANBI). 2012. 2012 Vegetation Map of South Africa, Lesotho and Swaziland. NVM2012beta2_wgs84_Geo. [Dataset]. Pretoria, South Africa.

South African National Biodiversity Institute (SANBI). 2016. Lexicon of Biodiversity Planning in South Africa. June 2016. South African National Biodiversity Institute, Pretoria. 58 pages.

Statistics South Africa (Stats SA). 2000. Water Accounts for South Africa. Discussion document (D0405.1), Statistics South Africa, Pretoria.

Statistics South Africa (Stats SA). 2004. Natural resource accounts – Water accounts for nineteen water management areas, 2000. Published 29 January 2004. Document 04-05-01. Statistics South Africa, Pretoria.

Statistics South Africa (Stats SA). 2006. Update water accounts for South Africa, 2000. Published 5 December 2006. Statistics South Africa, Pretoria.

Statistics South Africa (Stats SA). 2009. Water accounts for South Africa, 2000. Published 31 March 2009. Statistics South Africa, Pretoria.

Statistics South Africa (Stats SA) 2010. National accounts: Environmental economic accounts: Water management areas in South Africa. Discussion document (D0405.8), Statistics South Africa, Pretoria.

Statistics South Africa (Stats SA). 2020. Natural Capital 1: Land and Terrestrial Ecosystem Accounts, 1990 to 2014. Discussion document D0401.1. Produced in collaboration with the South African National Biodiversity Institute and the Department of Environment, Forestry and Fisheries. Statistics South Africa, Pretoria, South Africa.

Statistics South Africa (Stats SA). 2023. Natural Capital Series 3: Accounts for Strategic Water Source Areas, 1990 to 2020. Discussion document D0401.3. Produced in collaboration with the South African National Biodiversity Institute and the Department of Forestry, Fisheries and the Environment. Statistics South Africa, Pretoria.

Turpie, J.K., Letley, G., Schmidt, K., Weiss, J., O'Farrell and Jewitt, D. 2021. Towards a method for accounting for ecosystem services and asset value: Pilot accounts for KwaZulu-Natal, South Africa, 2005-2011. NCAVES project report: https://seea.un.org/content/knowledge-base

United Nations (UN). 2012. SEEA-Water: System of Environmental-Economic Accounting for Water. Department of Economic and Social Affairs: Statistics Division, United Nations, New York, USA.

United Nations (UN). 2014. System of Environmental-Economic Accounting for Water. Department of Economic and Social Affairs: Statistics Division, United Nations, New York, USA.

United Nations (UN). 2021. System of Environmental-Economic Accounting - Ecosystem Accounting g (SEEA EA). White cover publication, pre-edited text subject to official editing. Department of Economic and Social Affairs, Statistics Division, United Nations, New York, USA.

WWF-SA. 2017. Scenarios for the Future of Water in South Africa. World Wide Fund for Nature – South Africa (WWF-SA) and the Boston Consulting Group (BCG), Cape Town, South Africa.