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Water Supply Services: Biophysical Modeling and Economic Valuation in Ecosystem Accounting

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Description of water supply as an ecosystem service

The SEEA Experimental Ecosystem Accounting (EEA) framework, defines ecosystem services as the contributions of ecosystems to benefits used in economic and other human activities (UN et al., 2014). The existing SEEA-Water framework (UN, 2012) provides a detailed guidance for water accounting from the environment, i.e., upstream basins, aquifers and water bodies. However, it falls short of including the role of terrestrial ecosystems that contribute to the water exchanges between water resources within and outside upstream basin by regulating water quality, flows and storage. In this paper we demonstrate how the SEEA EEA approach extends the SEEA-Water framework to account for freshwater ecosystem services that are essential for reliable water supply as the final service to a range of economic sectors including households.

Water supply is a provisioning service describing water used for extractive and *in situ* purposes (Brauman et al. 2007). Current approaches to organize the analyses of water supply services from ecosystems can be divided into two main groups: organised by typology of ecosystems (Grizzetti et al. 2016) or ecosystem functions (De Groot 2002). The first approach considers water supply as water made available by ecosystem assets (e.g., rivers, lakes or aquifers). The second approach considers the impact of ecosystems on four ascepts of water supply. Namely, quantity[1] (i.e., the absolute volume of water), timing and location of flow (distribution of water quantity over a year and region), as well as water quality (De Groot 2002; Brauman et al. 2007). This stems from the expectation that demand from benefitiaries for water supplies will be based on claims of a certain volume of water, of a expected quality, and at a certain place and time (Brauman et al. 2007). When considering this second prespective of ecosystem functioning, we

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[1] Water quantity in this paper is used as synominous of water yield that is defined as the average amount of freshwater that runs off in an watershed via streams and rivers. According to the Manual of Hydrology of the US geological Services (1960), “the runoff from the drainage basin, including ground-water outflow that appears in the stream plus ground-water outflow that bypasses the gaging station and leaves the basin underground. Water yield is the precipitation minus the evpotranspiration” (https://water.usgs.gov/wsc/glossary.html#Wateryield). Water quantity and water yield differs from the definition of water supply that relates to amount of water use as indicated futher in the text.

consider in this document quantity, timing and location as the three attributes of water supply because water quality is covered in a related ecosystem service document.

1.1. Common nature of water supply

The ecosystem service of water supply refers commonly to the amount of water being used by different economic sectors and households (Grizzetti et al. 2016). It focuses on the volume of water abstracted as a material input for production and consumption and as a "sink" for waste. "Abstraction is defined as the amount of water that is removed from any source, either permanently or temporarily, in a given period of time for consumption and production activities" (SEEA-Water pg. 45). Water sources for abstraction includes inland water resources (rivers, lakes, artificial reservoirs, groundwater, glaciers, snow and ice), sea water, direct collection of precipitation, groundwater and soil water. The last item refers to water use in rain-fed agriculture (SEEA-Water pg. 46).

Three main water flows within the economy are considered in the SEEA-Water framework: (1)"all inland water resources from which water is, or can be, abstracted"; (2) "water exchanges between water resources within the territory of reference, such as infiltration, run-off and percolation"; and (3) "water exchanges with water resources of other territories, that is, inflows and outflows. Exchanges of water between the water resources are also referred to as natural transfers" (SEEA-Water pg. 21).

The SEEA-Water framework accounts only for the water that is physically removed from the environment, i.e., upstream basins, aquifers, and water bodies that is then used in activities involving production and consumption (e.g., water harvesting such as rainfed agriculture and generation of hydroelectric power). In that context, it does not account for other "non-consumptive" use of water directly related to water supply under the scope of quantity, timing and location, such as, infiltration, storage, navigation, aesthetic, cultural and recreational uses.

Water in its natural environment used for recreational good or service and water that is important as habitat for all living beings, including human, is not considered under the SEEA-Water (SEEA-Water pg. 19). Further, the SEEA EEA seems to be limited only to ecosystem services where there is a direct link to human well-being (UN et al., 2014, p. 20). Therefore, inclusion of water for other uses need further discussion because water supply for those uses can be an element in the production function.

In summary, the EEA approach goes beyond the SEEA-Water framework because it accounts for ecosystems beyond aquatic assets (rivers, lakes or aquifers etc.) and considers ecosystem functioning of terrestrial ecosystems to support water supply, and explicitly including aspects of supply, quantity, location, timing, and quality.

In this paper we define water supply as the amount of water that is used as material input for activities to the production of benefits to economic users for consumptive purposes (including households, firms and the government), and non-consumptive purposes that is dependent on ecosystem capacity (quantity, timing and location) to provide the required amount of water. This definition is similar to how CICES V5.1, 18/03/2018 describes water supply: a water provisioning service used by humans to obtain nutrition, materials or energy (including, water for drinking, energy production, and non-drinking purposes) (European Environment Agency, 2018). We broadly define *similar and related ecosystem services* as ecosystem services provided by terrestrial ecosystems that affect the characteristics of water supply.

1.2. Similar and related ecosystem services to water supply

The distinction of similar and related ecosystem services from water supply is important to prevent double counting in accounting. For instance, EEA states that water supply services combine elements of both provisioning and regulating ecosystem services (UN et al., 2014, p. 65). As highlighted above, water supply cannot be considered in isolation of water quality conditions (De Groot 2002; Brauman et al. 2007); an abundance of water that can be made available for humans, but is of such poor quality that it is not ingestible, renders the water unusable and incapable of generating a benefit. Therefore, water quality is a direct related ecosystem service to water supply.

Similar and related services to water supply might be distinguished by determining whether water supply is an intermediary or final service. According to Boyd and Banzhaf (2007), such determination can be done by defining the benefits from water supply. For example, water regulation services, e.g., water purification by wetlands, are an intermediate input to the final service of clean water provision to human consumption. However, when fish production is the final benefit of interest, then water supply would move from being the final service to an intermediate one. Another useful example is water abstracted to cool the machines of a widget factory represents a benefit to the factory owner. For the household that consumes the widget, the water provisioning service was an intermediate input into the production of the final good and thus water is not considered a direct benefit to the consuming household. In other words, whether the service is considered final or intermediate will change depending on who the beneficiary is (Fisher et al. 2009 and see Boyd, 2007 for a full treatment of benefit dependence). Therefore, it will be important to clarify whether related ecosystem services should include all those services to which water supply services is an intermediate input. The Final Ecosystem Goods and Services Classification System (FEGS-CS) (Landers and Nahlik. 2013) may be also helpful in determining if water supply is an intermediary or final service while linking final ecosystem services to specific beneficiaries.

The conventions established by CICES V5.1, 18/03/2018 is also useful to list potential similar and related services to water supply more especifically. Based on the discussions above, the list includes: (i) biotic regulating and maintenance services which include, mediation of wastes/toxic substances through bioremediation (CICES code 2.1.1.1) and filtration (2.1.1.2), regulation of baseline flows and extreme events (2.2.1.3), regulation of fresh and salt water conditions by living processes (2.2.5.1 and 2.2.5.2), and; (ii) abiotic regulation and maintenance services that include the mediation of waste, toxics and other nuisances in freshwater/marine ecosystems (5.1.1), regulation of baseline flows and extreme events (5.2.1.2).

1.3. Benefits and boundary for water supply

1.3.1. Benefits

Benefits under the SEEA EEA framework are defined as SNA benefits and non-SNA benefits to follow conventions of the SEEA-Water framework (UN 2012). SNA benefits are goods and services that are consumed and are produced by economic units. The measurement boundary is defined by the production boundary used to measure gross domestic product (GDP) in the SNA and includes also goods and services produced by households for own consumption. Non-SNA benefits are benefits enjoyed by individuals but are not produced by economic units. These benefits are not the result of production processes as defined by the production boundary of the SNA. In most circumstances, SNA benefits are those that can be traded in the market while non-SNA benefits generally cannot (UN et al., 2014, p19; SEEA, 2018). Beyond consideration of benefits as SNA or non-SNA, EEA suggests distinguishing those ecosystem services that contribute public vs private benefits. Thus, three classes emerge: (i) ecosystem services generated from economic assets that are private or publicly owned generate private benefits; (ii) ecosystem services generated from private assets that produce public benefits, and; (iii) ecosystem services generated from assets that are not privately owned and contribute to the generation of public benefits. Considering SNA and non-SNA benefits and these three classes, the specific benefits related to water supply services should be delineated for clarity.

Table 1 below lists benefits associated with SNA economic activities for the ecosystem service water supply, according to the SEEA-Water, and provides a first attempt to classify water supply as intermediary of final service based on benefits being provided by water use. However, to fully capture EEA recommendations those SNA economic activities listed in Table 1 might be further classified into public vs private benefits.

1.3.2. Boundaries

The SEEA-Water framework defines boundary broadly as all inland surface water bodies (rivers, lakes, artificial reservoirs, glaciers, snow and ice), groundwater and soil water (SEEA-Water pg. 27). For accounting purposes, SEEA-Water indicates that, since priority should be given to the spatial scale of conventional economic accounts and economic information that is compiled according to SNA, a broader boundary should be considered to be the country of interest (SEEA-Water pg. 36). As Vardon (2014) points out, a key distinguishing feature of EEA vs. SEEA and SEEA-Water is that in EEA spatial units are the basis for the accounting.

The EEA defines three main types of spatial units which serve as the statistical units for which ecosystem accounting data is compiled: 1) basic spatial units, 2) land cover/ecosystem functional units, and 3) ecosystem accounting units. Basic spatial units are typically small areas, for example 1 km^2 in size or the size of a pixel or parcel. Land cover/ecosystem functional units satisfy a set of criteria relating to the characteristics of a unit such as land cover/ecosystem type. The third type of spatial unit is the ecosystem accounting unit which is defined according to the purposes of the accounting such as administrative boundaries, watersheds and other types of boundaries. These areas should be generally permanent.

The SEEA-Water acknowledges the fundamental importance of using river basins for water supply accounting. It explains that the boundary might represent, for instance, an administrative region composed of several river basins, or several administrative regions that cover an entire river basin (SEEA-Water pg. 39). Despite the fact that SEEA-Water suggests that accounts should incorporate the watershed scale into the boundary, it does not incorporate the ecosystem's or hydrologic role of catchments in controlling water provisioning. Therefore, SEEA-EEA approach extends the SEEA-Water framework by accounting for ecosystem services provided by all ecosystems located within a hydrologically connected boundary, e.g., water basin or aquifer recharge area, contributing to the water supply as the final service (although to different degree depending on their functioning) (Brauman et al. 2007). In other words, the ecosystems within these boundaries not only include waterbodies but they also the adjacent hydrologically connected ecosystems that control the amount, timing and quality of water that is available for abstraction, hence affects the ecosystem assets and water supply *per se*.

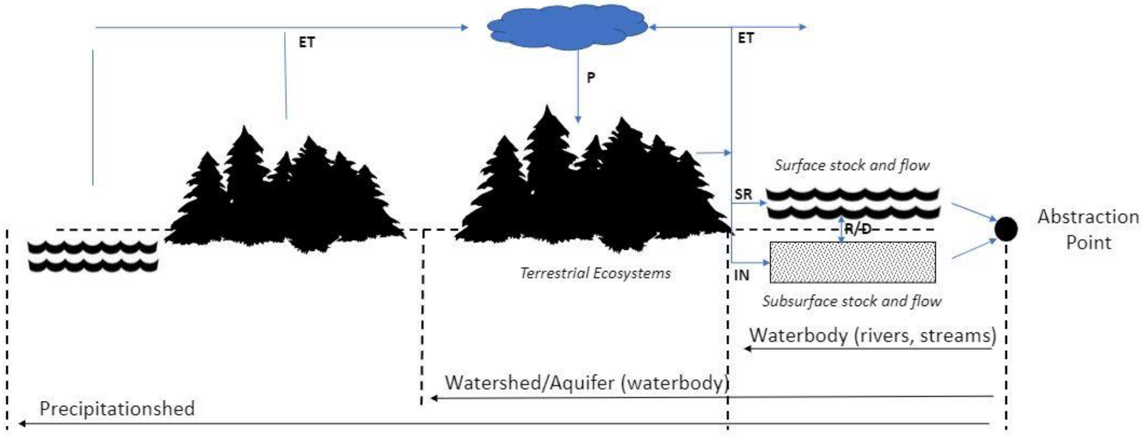
Three main boundaries might be drawn to depict the hydrologically connected ‘scape (i.e, domain for accounting impact): 1) waterbody, 2) watershed and aquifers, and 3) “preciptationshed”. The waterbody ‘scape refers to any body of water forming a physiographical feature, e.g., rivers, streams, lakes, aquifers, and seas. This is equivalent to what SEEA-Water framework defines as assets.

The watershed and aquifers ‘scape extends the domain of waterbodies to the regions that contribute to their flow/recharge.The watershed scale (or catchment scale) refers to the drainage basin, that is “a part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water” (Glossary of Hydrologic Terms, U.S. Geological Service). Recent reviews have regarded the watershed ‘scape as the appropriate scale to observe and quantify processes related to the water cycle, hence, to quantify and value water-related services (Grizzetti et al. 2016).

While watersheds capture the surface movement of water, the aquifer ‘scape looks at sub-surface flow and is especially important for groundwater dependent regions. This is key because groundwater divides do not necessarily correspond to surface water divides and global groundwater depletion has doubled since 1960 (Wada and Bierkins, 2010) primarily due to withdrawals for irrigation (Dalin, 2017). Groundwater use, particularly in transboundary basins, is complicated by the fact that aquifer boundaries shift with use intensity and depend on intrinsic permeability of geological material of aquifers and local conditions (Reeves, 2010). In contrast, watershed boundaries correspond to surface water divides which is delimited by the highest points in a spatial area (and are therefore not subject to change with use intensity as groundwater boundaries are).

The “precipitationshed” with a much broader scope refers to the recycling of moisture over land surface where evapotranspiration from one region drives precipitation in another. For example, studies show that up to 70% of the rainfall for the Río de la Plata Basin in Argentina/Uruguay originates as evaporation from the Amazon forest (Van der Ent et al., 2010). Despite the ubiquitous importance of the “precipitationshed” for water supply, this type of boundary is likely difficult to be used in the accounting context because of its high variability in time and scape.

The Figure 1 illustrates the relationship between the three biophysical scopes, while connecting with the water cycle and the relative influence on water quantity. In SEEA EEA, the various ‘scapes boundaries mentioned above, should be expressed in terms of either the basic spatial units, land cover/ecosystem functional units and ecosystem accounting units. Note that, treatment of sea water within the SEEA-Water is unclear. Although sea water for desalinization is provided as an example along several places in the SEEA-Water document and being included in the standard use and supply tables, sea water is not included in the list of water resources as asset boundary.



P: Precipitation; ET: Evapotranspiration; SR: Surface Runoff; IN: Infiltration; R/D: Recharge/Discharge

Figure 1: Relationship between waterbody, watershed, and “precipitationshed” scales

1.4. The key users and beneficiaries

Following the guidelines of SEEA-Water, users and beneficiaries should be defined based on the International Standard Industrial Classification of All Economic Activities (ISIC) to align with the SNA. The following ISIC divisions and related economy fields are included.

- ISIC divisions 1-3, which include agriculture, forestry and fishing;
- ISIC divisions 5-33 and 41-43, which include mining and quarrying, manufacturing, and construction;
- ISIC division 35: electricity, gas, steam and air-conditioning supply;
- ISIC division 36: water collection, treatment and supply;
- ISIC division 37: sewerage
- ISIC divisions 38, 39 and 45-99, which correspond to the service industries.

Although it is recommended that SEEA-EEA use the same user structure as in the SEEA-Water, *ISIC division 37: sewerage* might be excluded because it is beyond the scope of work described in this paper as it corresponds to water that is returned to the environment. Table 1 below lists the economic activities we considered for ecosystem services water supply.

SEEA (2018) imply that user might be used interchangeably with beneficiary: “in each sequence of use of ecosystem services and production of benefits there is an associated user or beneficiary being an economic unit – business, government or household.” However, SEEA-EEA may consider the environment as a beneficiary in supporting ecological functions, which is a concept that needs further investigation to understand the specifics of how to include it in accounting systems.

Table 1. List of users (economic units) and associated benefits for water accounts based on SEEA-Water framework. In bold economic activities and benefits that abstract water directly from the environment (to be supplied to other economic activities). In bold and italic economic activities that may abstract water directly from the environment or use water already in the economy (supplied by other activity).

Economic Activity (SEEA-Water/SNA)	Benefits (not exhaustive)
ISIC divisions 1-3, which include agriculture, forestry and fishing	***- Agricultural product (cereals, fruits etc.)*** ***- Live stocks*** ***- Trees*** ***- Paper*** ***- Logging*** ***- Capture fishery***
ISIC divisions 5-33 and 41-43, which include mining and quarrying, manufacturing, and construction	***- Petroleum*** ***- Coal*** ***- Natural gas*** ***- Metal ores*** ***- Stone*** ***- sand*** ***- Clay*** ***- Fertilizers***
ISIC division 35: electricity, gas, steam and air-conditioning supply	***- Electricity***

ISIC division 36: water collection, treatment and supply	- **Water**
ISIC divisions 38, 39 and 45-99, which correspond to the service industries	- ***Manufacturing products*** - **Inland water transportation** - Food service activities

Measuring water supply

The SEEA-Water uses ‘physical supply and use tables’ to describe water flows in physical units within the economy and between the environment and the economy (SEEA-Water pg. 41). For accounting purposes, supply is equal to the use or receipt of the services during an accounting period. In other words, the quantity of service extracted from the ecosystem must equal the quantity used by the economic unit (SEEA 2018).

While it seems reasonable to use the same rational used by SEEA-Water to quantify the water use of different users, the question is whether the ecosystem’s function to provide usable water is implicit in the quantification of the water supply *per se*. SEEA-EEA needs to attribute the water abstracted with the ecosystem(s) supporting its supply, which is made possible when considered one or more land cover/ecosystem functional units. Also important in the context of EEA are the inter-ecosystem flows of water.

Quantification of water supply for accounting purposes also consists of integrating hydrological information with economic information, thus the temporal and spatial references of the two sets of data must be reconciled. Considering the three spatial units in ecosystem accounting, quantification requires reconciliation of land cover/ecosystem functional units with ecosystem accounting units. Natural features of the landscape that are reflected in land cover/ecosystem functional units rarely coincide with the administrative boundaries that may be the basis of an ecosystem accounting unit. The Australians and the Center for Policy Studies have considerable experience with reconciling watershed boundaries with administrative ones (Wittwer 2012).

In terms of temporal scale, it is recommended that the reference period for the compilation of the accounts be the same 12-month accounting period as that of the national accounts. Depending on the data available, disaggregation of the data into smaller temporal scale is possible, and useful to highlight seasonal variability in water supply. Further consideration could be focused on reconciling temporal/seasonal changes in ecosystem’s function to supply water with temporal changes in use/demand. From a budgetary perspective, it might be important to reflect the long-term hydrological cycle (longer than a year) by using an average year in a series of years of long enough duration to be stable (20 or 30 years) to provide information on the average annual water availability in the environment (SEEA-Water pg. 39).

1.5. Relevant ecosystem characteristics and enabling conditions

Several factors control the amount of water (water yield) in a particular ecosystem, including climate, soil type, slope, and vegetation type and age, and management practice. As there is a long-standing debate over the impact of restoration on water yields, this session focus on the roles of terrestrial ecosystems with respect to the service of water supply. Note that this topic is complex and the following aims at providing a general overview of the matter.

Evapotranspiration (ET) is a major component of the water balance influenced by terrestrial ecosystems (Chang 2006). Hence, one of the principal effect of ecosystems is to regulate the available quantity through direct use of water by plants. Trees generally use more water than shorter vegetation because of higher ET rates in forest systems (Calder 1998). The total volume of surface and groundwater available from forested watersheds is lower than that from grass or shrub-dominated watershed (Andressian 2004). It is well known that when grasslands are converted to forest, annual stream flows reduce and when forests are converted into pastures and over land covers, annual water yields increase. Changes in vegetation type will affect not only mean annual flow, but also the variability of annual flow (Brown et al. 2005). Therefore, while managing water supply, it is crucial to have an integrated perspective of the land cover. For instance, in water-scarce environments, vegetation with lower water requirements is likely to provide greater water supply benefits than those provided by a higher water-use ecosystem (Brauman et al. 2007).

Prevalent local climatic conditions and its interaction with vegetation and soil exert key control in the available amount of water as streamflow. Cloud forests are a typical example of this interaction and have reputation as suppliers of high amounts of streamflow throughout the year (Bruijnzeel et al. 2010). This is because stream water yields in cloud forest ecosystems can exceed precipitation inputs (runoff coefficient (streamflow/rainfall) > 100%). The very high streamflows have been primarily attributed to unmeasured inputs of cloud water (Zadroga 1981, Caceres 1981, Calvo 1986). Other montane ecosystems, such as the Paramo, are also particular examples of the key hydrological function that undisturbed ecosystem play in controlling water yield. The Paramo vegetation provides an intercepting surface for high amounts of drizzle that combined with low evapotranspiration rates results in high amounts of water transmitted into the soil, and high-water retention capacity. This climate-soil-plant integration is fundamental to regulating the water availability for systems that depend on the water supplied by the Paramos (Aparecido et al. 2018).

Terrestrial ecosystems arguably provide a stable supply of high-quality water that may be used for downstream irrigation, drinking water, industry, or hydropower generation. Therefore, the condition (preserved or degraded) of these ecosystems that control the quantity and timing of water availability for use directly influence water supply as a service. Given extensive debate on the role of forests in providing a diverse of ecosystem services, we provide Box 1 with additional information on these systems.

As the characteristics of the ecosystems *per se* influence changes in these characteristics affect the effectiveness of these systems in providing water. Climate change affecting the frequency and intensity of rainfall events, for instance, is key because it influences the timing and distribution of rainfall events, hence affects water availability. Less frequent but more intense, high volume rainfall events might result in more sporadic high-volume water yields, particularly in agricultural and pasture fields due to compacted soils. Furthermore, changes in soil conditions – either through compaction or erosion, driven by changes in rainfall patterns or land cover – can in turn modify the partitioning of water in surface and sub-surface components; leading to altered location and timing of available water supply. It has been reported that soil conditions from multiple decades of degradation influence the rate of recovery of key hydrological processes in restored forests (Bonell et al., 2010).

Box 1: Role of forests ecosystems on water yield

Forests and water are indistinguishably interlinked (Andréassian, 2004), and the negative impacts of deforestation on water resources are well documented (Andréassian, 2004; Bruijnzeel, 2004; D'Almeida et al., 2007, Aubertin and Patric, 1974; Williams and Melack, 1997; Dessie and Bredemeier, 2013; Vörösmarty et al., 2015). While it is reasonable to assume that the reverse of the deforestation process through forest restoration should have a general positive effect on water resources (Scanlon et al., 2007; Le et al., 2014), a long-standing debate, when considering the attribution of ecosystems for freshwater-related services, is over their impact on water quantity, timing and location.

Impact on yield: Deforestation at the local scale generally increases water yield due to substantial decrease in ET rates (Bruijnzeel, 2004). Even degradation of cloud forest ecosystems can lead to increases in water yield when cloud water interception is low and forest water use comparatively high (Muñoz-Villers, 2008, Gomez-Cárdenas, 2009). However, deforestation at the large scale can potentially reduce water yields by decreasing rainfall via atmospheric feedbacks (Coe et al., 2013). Therefore, there is support for both sides of the argument about how forest cover reductions might affect water yield. In terms of the impacts of restoration, in most cases of increased forest cover lead to a decrease in annual water yields, baseflow and groundwater, at least temporarily (several decades) (Filoso et al., 2017).

Impact on timing and location of delivery: The role of vegetation in partitioning flows in surface and sub-surface components is well established. Forest ecosystems regulate the transfer of surface water to groundwater by high rates infiltration, and generally increase the predictability of water yield by magnifying baseflows (Smakhtin, 2001). Therefore, upland forests are critical ecosystems that regulate the amount of water available for use downstream use. Increases in forest cover has been attributed to improve infiltration besides protecting the soil layer (Filoso et al., 2017). Increased soil infiltration is a key outcome from forest cover restoration as it can result in higher groundwater recharge (Buttle 2011, Perkins et a. 2014). However, quantifying impact on groundwater storage itself is complex due to interacting processes of infiltration, transpiration, soil moisture changes, etc., and predicting changes in groundwater recharge based on infiltration rates can result in large errors. On the other hand, new findings in moisture recycling (Keys et al., 2016), indicating that transpired water may at times form a significant percent of the precipitation on land, has added yet another aspect of contributions from terrestrial ecosystems that is largely unquantified.

Highlight: further discussions are highly needed to address the role of undisturbed versus disturbed ecosystems because it likely has direct influence on valuation mechanisms. From a purely ecological standpoint, forests and any other ecosystems in its undisturbed condition play a particular role on water yield, i.e., not positive or negative. The extent or direction of the ecosystem's role within the ecosystem services umbrella depends on human's expectation (or use)—it is only when ecosystems are disturbed that the role played by ecosystems can be 'felt' by humans. As highlight previously, an increase in water yield might be perceived as a positive effect from deforestation in some areas. However, because such water increase is commonly associated with negative consequences (e.g., increased erosion, reduction in water quality, increased flood risks, etc.), the positive value of such increase is unrealistic. Thus, monetary valuation of services provided by disturbed systems need to be evaluated differently from the service provided by 'intact' ecosystems. Similarly, as extent and quality of services provided by restored systems can be fundamently different (at least temporally) from undisturbed ecosystems, monetary valuations must take that into account.

1.6. Metrics for measuring water supply in physical terms

In hydrology, several metrics are used to measure water availability hence water supply. Most common are metrics in form of volume per unit time such as: discharge, volumetric flow rate of water (volume per unit of time, m^3/s, ft^3/s). Other metrics include discharge per unit of area; annual runoff (volume); water yield (volume) or 'stock' (volume) per year.

1.6.1. Pathways to attribution to ecosystems

This section provides insights on how to consider the ecosystem's function to support water supply while measuring the ecosystem service flow.

At a waterbody 'scape: approaches may apply direct attribution to the inland water bodies and aquifers from which water is abstracted without directly considering ecosystems upstream contributing to sustaining that flow. The total valuation of any waterbody will therefore be directly linked to the total usable water it provides. By including environment as a beneficiary in the assessment with its non-consumptive water usage, such an approach may incrementally build on SEEA-Water; and mitigate some of the risk of unsustainable water supply abstraction.

At a watershed or 'aquifer-recharge area' 'scape: to attribute the role of terrestrial ecosystems to regulating supply, 'tracking' of flows through the hydrological system is important. Two approaches are considered below, with an example for the former described in section 5. Both approaches are sensitive to model assumptions on parameters such as interception, infiltration, etc. For both of these, delineation of ecosystems that contribute to the volume of the main waterbody (surface or sub-surface) will have to be based on an estimated contributing area routing precipitation. For surface water features, a watershed derived from digital terrain models can give a decent estimate of contributing areas. However, for groundwater, identifying recharge pathways for aquifers requires *in-situ* observations and geological studies.

> **Modelled runoff generated over land-cover:** for the watershed above any given abstraction point, the runoff generated from modelling is 'binned' according to the landcover providing estimates of contribution from each landcover type. The underlying assumption here is that the terrestrial ecosystem is regulating the timing of the supply without explicitly accounting for or modelling it. The advantage of the method is that it is relatively straightforward to apply using most rainfall-runoff models. The main disadvantage is they generally focus on only surface flow with regulating features estimated through calibrated or uncalibrated parameters.
>
> **Modelled partitioning of flow:** this approach attempts to account for ecosystem' influence (and the soil layer they protect) in partitioning of flow into the "quick" surface runoff and "slow" shallow/sub-surface flows. In principle, this "slow" component may then: 1. contribute to baseflow of surface water systems, improving timing of water availability; 2. allow recharge to aquifers and explore alternate (and more extensive) flow routes for water, improving location and regional-range of water availability. Data requirements for this step is high covering both the surface and groundwater domain, and delineation of contributing area will be different for surface and subsurface features

At "precipitationshed" 'scape: extend to include ecosystems that contribute to the moisture through evapotranspiration that is eventually recycled as precipitation over the watershed/aquifer-recharge area. The UN World Water development report (2018) estimates that globally, up to 40% of terrestrial rainfall originates from upwind plant transpiration and other land evaporation. With this source accounting for most of the rainfall in some regions, terrestrial vegetation may be re-cast as water-recyclers rather than water-consumers.

1.6.2. Summary of common data sources and models for physical flow estimates

Estimation of physical flows of water supplies depends on estimating the demand and/or actual water use to produce a particular benefit. Methods for estimating demand can be broadly classed as irrigative and non-irrigative use of water. Nazemi and Wheater (2015a) provides a review of obtaining estimates of these from both top-down and bottom-up data sources. The Table 2 below summarises the approaches demonstrated in literature for estimating irrigative demand for a region. Unlike irrigation demand, top-down approaches have been widely used for non-irrigative withdrawals to transfer national or geopolitical data to basin or grid scales. Various downscaling procedures have been suggested, based on different proxies. Please see Tables 4, 5 and 6 of Nazemi and Wheater, 2015a for a comprehensive description of these approaches.

Table 2: Estimating Irrigative Water Demand (based on review by Nazemi and Wheater, 2015a)

	Summary of available Methods
Top-down estimation of Irrigative Demand	• Downscaled from census-based inventories such as FAO’s Information System on Water and Agriculture (AQUASTAT; http://www.fao.org/nr/water/aquastat/main/index.stm), which provides annual inventory data on national (and in some cases also sub-national) scales. • Outputs from socio-economic models such as Global Change Assessment Model (GCAM; Wise and Calvin 2011), which estimates agricultural production based on socio-economic variables, from which the irrigation water use is indirectly calculated using the water required for each crop per unit of land. • Application for a global/regional hydrological model (e.g. PCR-GLOBWOB) and subtracting estimates for groundwater extraction from a regional data base and forcing it with a climate data set.
Bottom-up estimation of Irrigative Demand	Grid-scale estimation of demand based on crop type and estimation of evapotranspiration is modelled, some methods include: • Amount required to bring soil-moisture at root-zone to saturation • Amount required to bring soil-moisture during growing season at (or a constant percentage of) field capacity • Difference between crop-dependent potential evapotranspiration & available crop water • Dynamic vegetation growth models coupled with potential transpiration estimates

Estimating water availability in terms of discharge or storage available maybe directly made by *in-situ* measurements of surface water and groundwater resources. Remotely-sensed datasets may help expand the coverage of the estimates by use of mathematical models. More complex model may incorporate the demand estimates from above to directly model supply from ecosystem services. The Table 3 below is a brief review of the type of data that maybe available or models used by water resource managers/academic institutions highlighting some common attributes.

Table 3: Estimating water availability

Type	Examples	Attributes
In-situ surface water monitoring	• River elevation gauge • Slug test • Acoustic Doppler Current Profiler (ADCP)	Point based estimates; Most accurate; Labor intensive
In-situ groundwater monitoring	• Monitoring wells • Slug test • Electromagnetic (EM) measurements such as time-domain EM (TDEM)	Locally accurate; Expensive; Labor intensive
Remotely-sensed water cycle components	• Precipitation: CHIRPS/GPM • Groundwater storage changes: Grace • Landcover, evaporation: MODIS, LandSat • Soil moisture: Sentinel, SMAP	Comprehensive; freely available and global in coverage; sparse historic coverage; generally, coarse resolution and medium/low accuracy
Hydrologic modelling of waterbodies/watershed	• Hydrological models (such as SWAT, Topmodel, Mike SHE) • Groundwater models (such as MODFLOW) • Coupled surface water and groundwater models (such as PARFLOW) • River flow models (such as HEC-RAS) • Ecosystem service models (such as InVEST, ARIES)	Data intensive; valuable if locally calibrated; can be customized locally and used to generate scenarios; possibility of parameter bias
Regional/Global models resolving water cycle components	• Global hydrological models (review: Sood and Smakhtin, 2015) • Land surface model (such as VIC) • Regional/global river routing models (review: Shaad, 2018)	Global coverage; coarse resolution; results are freely available; not validated locally;

Measuring future flows of water supply

The SEEA-Water framework does not provide guidance in terms of the changes in the ecosystem condition and the capacity to supply water. However, tracking long-term use and supply tables of SEEA-Water should in theory be useful to assess changes in water volumes (stocks) over time.

Catchment assessments incorporating all attributes governing water yield as indicated previously are highly recommended to estimate future water availability to supply. Water yield responses to changes in those variables (in relation to "pristine" conditions) occur at several spatial scales (ranging from drainage networks to reaches to streambed patches) as well as at different temporal scales.

1.7. Scenario Development & Mathematical models

Developing future scenarios and evaluating changes via them have been a prominent strategy by development and planning agencies to capture risk and convey possible trajectories of growth. Developments of decision support systems based on geographic information systems (GIS) and mathematical models of hydrological systems have provided practical and useful tools to estimate water yields given future scenarios.

Future scenarios considered under such planning framework are increasingly been derived from stakeholder consultation revolving around actual outcomes of conditions in the basin. Although, not exhaustive, they provide a more grounded alternate to 'unrealistic' or extreme scenarios (such as all vegetated landcover in a basin replaced with bare soil).

As stated before, measuring future flows of water supply hinges on considering linkages between different attributes of the ecosystems and water yield. The influence of terrestrial ecosystems, particularly forests, on water supply have at times been the subject of public debate, and the scientific literature is very rich in these topics. The range of mathematical models available to consider these linkages, build on varying assumptions and parametrisations of the functioning of ecosystems, have a significant impact on the predicted outcome. Ideally, a study to measure changes in future flow will have the capability to carry out either (1) validation of the selected model (against observed data) for its capability to capture the change in condition it will be used to project; or (2) derive results from an ensemble of models build on varying assumptions of ecosystem functioning.

Developing suitable mathematical models appropriate to scale and processes and forced by data comparable in quality is an investment of resources and time. It is not uncommon to have "modeller fatigue" where after a long process of developing models, they are scarcely used before being filed away. With wide-scale adoption of cloud computing and storage, adoption of strong guideline of documentation and recoding metadata; allowing model reuse and update will be of benefit to maintain repeatability and update of assessments.

Economic valuation of water supply and service supply chain

This section summarizes some key takeaways from water provision and regulation context from extensive discussion in SEEA-EEA. We provide a brief inventory of literature with representative case studies; discuss valuation methods and techniques including their strengths and weaknesses; identify some key data needs and sources; and finally, highlight outstanding issues for further discussion.

Economic valuation for ecosystem accounting is not an independent exercise, rather an outcome strongly linked to a series of preceding measurement and modelling processes. An ecosystem provides water supply, which in combination with human and technological inputs translate into benefits to different beneficiary groups (Figure 2). These benefits are first measured in biophysical terms before monetary valuation. In developing these conceptual models, the first step is the identification of the main sources and water using sectors specific to the boundary in question.

The proposed ecosystem service supply chain for water supply has similar structure to the SEEA-Water in the sense that the assets are the waterbodies (rivers, streams, lakes, groundwater etc.), the ecosystem service is the amount of abstracted water for use in economic units and households, and the benefits are those goods, products and services produced by economic activities, where SNA benefits are concerned, as well as non-SNA benefits. A critical extension to a physical water asset account (UN et al., 2014, p. 81) is its recording of inter-ecosystem water flow. This may not be important in the context of SEEA-Water, but given the spatial specificity of ecosystem service accounting, it is indeed relevant.

It is important to note that the valuation of water supply might not be necessarily identical to valuation of its associated SNA goods and services. Water is usually characterized as being a common pool and having an open access nature to a wide range of beneficiary groups (from individuals to businesses to society). Similarly to a bank account, there is a maintainable rate of outflow (including societal use) which, if exceeded, could lead to resource depletion.

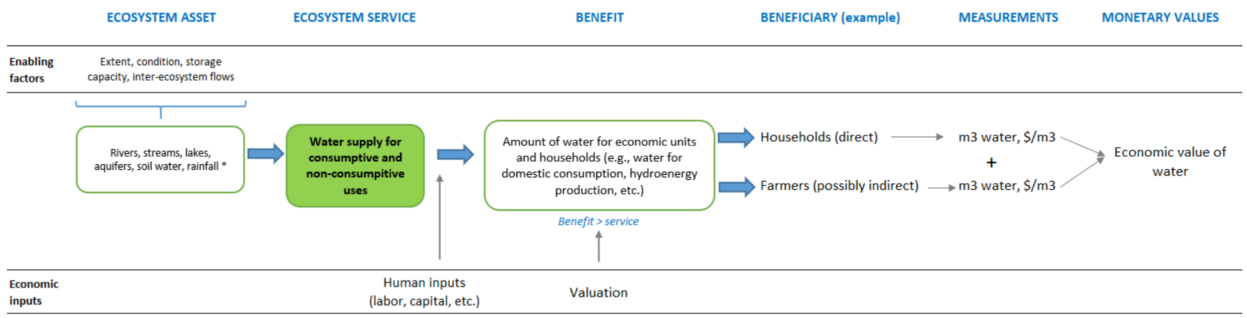


Figure 2. Logic chain for water supply. Note that seawater might become an asset when desalinization plants exist

1.8. Valuation techniques for water supply

SEEA-Water provides general guidance on valuation of water with examples of potential valuation techniques in practice. However, this technical document refrain from making any specific methodological recommendations, citing a lack of consensus among economists. Although valuation techniques discussed there and elsewhere in literature can be carefully applied in ecosystem accounting context, the main challenge is attributing monetary value to ecosystems as an asset. A consensus needs to be reached upon as to how some of the techniques are applicable in ecosystem accounting context given the complex inter-ecosystem and ecosystem-human interaction behind delivering water as a final benefit.

SEEA EEA technical and methodological guidance documents, published case studies and other relevant literature provide general guidance on monetary valuation of ecosystem assets and services in ecosystem accounting. These materials widely focused on suitability of different methods and techniques which are commonly found in environmental economics and ecological economics literature.

Valuation methods for water supply by different ecosystems depend on beneficiary-specific end use of water. Appropriateness of valuation techniques depends on a range of factors such as specific benefits, beneficiaries, data availability, time and resources availability, as well as desired precision. There are quite a few valuation methods which are consistent with SEEA guidance and SNA principles, while there are few others which are not. From end-use (i.e., final product) perspective there are three specific contexts for valuation (see SEEA-Water): (1)Water as a final consumer good; (2) Water as an intermediate input to production in agriculture and manufacturing; and (3) Water as vehicle for other ecosystem services such as wetlands biodiversity, waste assimilation.

It is now well recognized within the accounting community that the purpose of valuation, benefits and beneficiaries need to be understood, and choosing a valuation technique should not be the beginning priority. It is also important to recognize that valuation is context dependent. While valuation philosophy needs to be consistent with SNA principles for its direct integration, it is also recognized that to meet some purposes (e.g., policy support and post-accounting analytical needs, scenario analysis etc) traditional environmental valuation methods (e.g., welfare-based approaches) can be applied.

Table 4 below shows a sample of techniques for monetary valuation reported in valuation literature for water serices. Although any specific benefits can be measured in more than one technique, each technique has its own underlying assumptions and limitations, which can lead to vastly different monetary values.

Table 4: Commonly reported water services benefits and related valuation techniques

Services	**Benefits**	**Techniques**
Water supply	Household consumption	Demand function; sale and rental rights; alternative cost
	Municipal water	Demand function; sale and rental rights; alternative cost
	Irrigation	Residual value (e.g., net return to water); change in net income; production function
	Hydroelectricity generation	Production function; residual value
	Industrial inputs (e.g. beverage)	Residual value; demand function; production function
Flood protection	Households, farmers	Damage cost avoided; replacement cost
Water quality	Drinking water	Water purification cost; marginal cost of water degradation; abatement cost
Water flow regulation	Navigation	Lacks a consensus
	Recreation	
Biodiversity conservation	Biodiversity	

Other valuation techniques that are commonly and widely used in environmental economic literature (see for example Birol et al., 2006 for a comprehensive review of methods and techniques) that might be useful for water supply in ecosystem accounting to some extent. (1) Shadow pricing: Water markets are often distorted due to government regulations and subsidies. While a shadow price adjusts market price by addressing those distortions, such price adjustments are not consistent with the "exchange value" concept advocated for ecosystem accounting; (2) Contingent valuation: CVM is another most common technique used for water resources in literature (e.g., Orgill-Meyer et al. 2018), it seems the accounting community has reached to a consensus that this is an inappropriate method for ecosystem accounting; and (3) Statistical modeling: Regression-based approaches, benefit transfer & function transfer are often used in economic valuation literature. A large number of wetlands studies took this approach in water resources valuation (Chaikumbung et al. 2016). However, no consensus has been reached to what extent this can be accommodated in accounting.

4.2. Data requirements and data sources

4.2.1. Data requirements

Development of ecosystem accounts requires a large information base for biophysical and economic analysis. Data requirement from a biophysical perspective were highlight previously in the paper and this session focus on the specific requirements from a valuation standpoint.

Specific requirements for data depend on the methods and technique used for valuation. For example, valuation of household water consumption may need data on water use and utility bills while valuation for hydro-electricity generation requires other types of data such as revenue, variable costs, depreciation etc (Table 5).

There is a strong interdependence between biophysical modelling and monetary valuation and between physical flow accounts and monetary accounts. Flow accounts would need to incorporate deterministic and stochastic approaches to reflect direct flows (based on pre-defined assumptions and flow pathways) from natural sources to anthropogenic water using sectors and flows between water using sectors while in the economy (e.g., mining, domestic water supply, industry, agriculture, etc.) as well as cross-sectoral flows which are indirect/random (e.g., the impact of municipal pipe leakage on the actual amount of water available/used by the agricultural sector) which often times are not accounted for in physical analysis of valuation.

Table 5: Example of valuation techniques, indicators and data sources

Water users	**Valuation method**	**Data/Indicators**	**Data sources**
Water in agriculture	Net Return to Water (NRTW)	Crop yield Revenue Variable cost	Physical analysis of water use Ministro de Agricultura y Riego
Water in domestic and industrial use	Cost of production	Water use Water production Water billing Operating cost	Physical analysis of water use The World Bank (2012); SUNASS (2012)
Water in hydroelectricity generation	Marginal productivity	Total electricity generated Total water consumed Electricity tariffs	Physical analysis of water use Government data sources

Source: Conservation International, 2016

4.2.2. Data sources

Many of the data are available in different forms coming from different sources. Government statistics including agricultural census, household surveys, forest inventories, etc. collect valuable information on wide range of indicators relevant to monetary water supply accounts. It is generally expected that department of statistics would collect and manage those data, but we have seen that other government agencies and institutions also collect valuable data as part of different projects and initiatives. Some countries frequently collect environmental-economic data on water resources indicators which are available for immediate analysis.

In contrast, there are many data poor regions where even bare minimum data can be challenging to overcome. Sometimes data are available for different economic units (e.g., irrigation) but not for required statistical units. In many instances new data collection efforts are required for even a preliminary pilot study, which can be highly time and resource intensive. At the very least some global datasets and databases can be used for initial accounts development. Ecosystem services valuation databases such as ESP, EVRI, ESVD, Ecosystem Valuation Toolkit have rich data points from across the globe. However, given the limitations (e.g., Richardson et al. 2015) those data need to be carefully used in a context different from where they were originally collected.

Relevant case studies

Several important scientific papers and reports have been published over the last few years reporting on advances in ecosystem accounting through case studies from different countries and regions. Water supply and water regulation were a large part in many of those publications where conceptual and methodological issues related to monetary valuation were also discussed. We highlight two cases studies that directly quantify water supply and are representative cases on economic valuation of water and related ecosystem services (see for example Viscusi et al., 2008, Young 2010, Wilson and Carpenter, 1999, Chaikumbung et al., 2016)

In a case study in Limburg province (Netherlands), monetary accounting for groundwater extraction and drinking water provision was implemented (Remme et al. 2015). The study used a “replacement cost” method with a least-cost alternative instead of a “resource rent” because of the strongly regulated drinking water market. The technique was based on the difference of production costs between groundwater and surface water. Relevant data and indicators used were operating costs, cost of capital and depreciation cost (taxes not included) among others. The monetary value was presented both in spatially distributed maps and in accounting tables. The study emphasized why moving away from welfare-based approaches and fully focusing on exchange value may not reflect the true contribution of ecosystem services to human wellbeing, especially in the case of water; e.g., soil water that contributes to biogeochemical processes that contribute to agricultural revenues. In this example, these indirect benefits were not accounted for in the “exchange value” approach advocated for ecosystem accounting.

In a sub-national scale ecosystem accounting pilot study in San Martín, Peru, Conservation International (2016) developed ecosystem supply and use accounts for the supply of water. Following conventions described in SEEA EEA and SEEA-Water, the study estimated water use by different beneficiaries and implemented input share, cost of production and residual value approaches for monetary valuation. The valuation exercise specifically focused on three water usages: 1) agricultural irrigation, 2) domestic and industrial consumption, and 3) hydroelectricity generation. Specific methods used were: net return to water (for irrigation), cost of production (domestic and industrial use) and marginal productivity (hydroelectricity generation) (also see Table 5). The study relied on multiple data sources including data obtained from hydrological modelling, government generated data such as water permits, revenue, variable costs, operating costs, electricity tariffs, etc. The study developed monetary asset accounts for provisioning services, while highlighting the challenges and future work needed (e.g., asset life, choice of discount rate, the role of future flows, etc.) which are equally important for ecosystem accounting of water supply.

While most case studies focus on water supply from surface waters, there are also examples of monetarization of groudwater. For example, Fenichel et al. (2016) provide a guiding framework consistent with capital theory, indicating how to measure the value of groundwater in an “Inclusive Wealth” approach. Such approaches can also provide important insights in the discussion of measuring sustainability within ecosystem accounting community.

Key issues and challenges

There are many outstanding issues and challenges common to the monetary valuation of most ecosystem services, here we highlight a few which are specific to water supply context.

Monetary value of ecosystem assets and services to individuals or to society at large creates considerable complexity and adds to an already large list of challenges and issues. Asset is a function of capacity and condition, but capacity itself is a function of current stock and rate of change in growth (water balance in our case), whereas some of the regulating aspects of water (e.g., water quality, flood mitigation) depends on many other ecosystem characteristics and hydrological conditions (Sumagra et al. 2015). These all requires a high modeling based information coming with many uncertainties. It is a challenge to report asset value in monetary terms when there is much uncertainty associated with biophysical models and variability due to different modeling approaches and assumptions. Year-to-year changes in water asset value will likely be more sensitive to modeling uncertainties than actual on the ground changes in physical quantity of water.

In contrast to SEEA EEA proposal to use Net Present Value (NPV)[2] of expected ecosystem services flows as a measure of capacity. Hein et al. (2015) suggested that, especially for provisioning services, capacity account should include NPV of capacity rather than NPV of future ecosystem services flows. Despite the authors argument that this approach is consistent with physical "capacity account", such an approach can be deemed to be inconsistent with "monetary asset account" which is based on potential future benefits rather than potential supply.

Interestingly, Monfreda et al. (2004) advocated approaches for measuring what they call "biocapacity" based on demand and supply of natural capital. Although their approach is not consistent with EEA principles, but the discussion can shed some lights on commonalities in measurement principles (e.g., Hoekstra, 2009 for an extension of this concept to water footprint analysis context).

In SNA and Central Framework, economic valuation is limited to benefits that accrue to "economic owners" – the institutional unit entitled to claim benefits. But as noted in the technical guidance, ecosystems are not a participant in the market where the transaction between assets and economic units (i.e., beneficiaries) occur. A quasi-market value of some of the goods and services are possible, but no appropriate institutional mechanisms exist to determine goods that are public/common pool (e.g. water borne erosion prevention by ecosystems)

Market price or exchange value is what is consistent with natural accounting context, regardless of prevailing market conditions. However, as discussed earlier, water is often a highly regulated commodity and the market price is distorted. By adjusting to accommodate for this distortion (i.e., shadow price), it can better reflects reality but there are disagreements on whether this may be considered aligned with SNA "exchange value" principles.

Ecoystems provide a range of non-use and indirect use values (biodiversity, water quality) that are not captured in monetary valuation process. The role of ecosystems on water yield, as discussed in Box 1, illustrate the interlinkages between forest role in yield, timing and location, underlying important the importance of such ecosystems to production as an intermediate service rather than final benefit. Much of that is not captured in monetary value. The connection between water in ecosystems and water that directly benefits people is not often clear. Even if it can be measured in physical flows, the absence of direct connection to human activities may represent an important challenge in attributing a monetary value to such benefit.

Finally, there is a need to expand the debate on how to monetarily quantify water supply from undisturbed versus disturbed ecosystems as the extent and quality of their services are commonly fundamentally distinct.

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[2] Net Present Value (NPV) refers to of the expected (capital) service flows that the asset will provide over its lifetime (Hein et al., 2016)

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