Island style water accounting: Methodological suggestions from the case of Hawaiʻi

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***Kirsten Oleson*[1]**

[1] University of Hawaiʻi at Mānoa, Honolulu HI, USA

Summary of key points:

- We created pilot island water accounts for two islands in the US state of Hawaiʻi using local data
- Accounts identified vulnerabilities and opportunities in the water system, as well as key data gaps and overlap where multiple agencies were collecting the same information, and the compilation process catalyzed cross-agency discussions
- Key suggestions to improve the relevance of accounts for islands are: (1) Water accounts need to be sensitive to the aquifer and watershed geography of islands, pinpointing supply and use to these features, and be linked to quality. (2) The existential reliance on and intensive management of aquifers could qualify them as produced assets. (3) Economic users need to be further disaggregated to facilitate analyses and distinguish economic sectors, as do returns to the environment, which should also be place-based. (4) Decisions related to water need to reflect the multiple values of water, otherwise economic production will be prioritized at the expense of other uses and benefits.

Questions to the London Group:

- Do you agree with the suggestions?
- What modifications to SEEA-Water could address suggestions above?
- Are there any examples that have successfully addressed similar issues?

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Introduction

This paper is produced for the 30th London Group on Environmental Accounting to inform discussions about the 2025 update of the Central Framework of the System of Environmental Economic Accounting (SEEA). It raises issues related to water accounting that arise in small island systems, with an aim to ensure that water accounts are relevant to island systems and useful for policy in these fragile settings.

Island geography, economic and freshwater vulnerability, political economy, and socio-cultural values differentiate islands from continental systems, and as such, water accounts may require some adjustments to make them policy relevant and useful to decision-makers.

Freshwater on islands

Many mountainous volcanic islands are characterized by small, flashy watersheds and extreme precipitation gradients with heavy rainfall falling on the windward side and high elevations and arid conditions on leeward sides (Lau & Mink, 2006). A large portion of precipitation on these islands derives from fog drip in high elevations, where vegetation intercepts moist, trade-wind driven air (Giambelluca et al., 2011; Santamarta et al., 2014). Porous soils quickly transport water to aquifers, while steep topography quickly ushers remaining surface water to the coasts. Complex aquifer systems can extend across multiple watersheds, and be interconnected through lava tubes or isolated by dikes (Izuka et al., 2018). Freshwater springs percolate cool freshwater across the landscape. In low atolls, common in the north west of the state of Hawaiʻi and across the Pacific and Caribbean, water rapidly percolates to a shallow freshwater lens that floats on seawater (Werner et al., 2017).

Historically, islanders have relied on consistent rainfall, stored in natural and rainwater catchment systems, to meet their freshwater needs (Wallace & Bailey, 2015). Due to their geographic isolation, islands must be largely self-reliant. Water is scarce, and considered precious, even sacred (Wilson & Inkster, 2018). In Hawaiʻi, for instance, there is a god of water, Kāne, and an ancient song describing how water permeates all aspects of life; freshwater is power, life, and enables life (D. K. Sproat, 2010). The importance of water in the Hawaiian worldview is illustrated by the fact that doubling the word for fresh water, "wai" to "waiwai", means wealth.

Island economies are highly dependent on water. Many small islands tend to rely disproportionately on tourism, making them susceptible to shocks and environmental change (Gounder & Cox, 2022; Uyarra et al., 2005). Resorts with lush landscaping and green golf courses housing millions of tourists require immense quantities of water. Agriculture is another water-dependent sector. While many small islands still have agriculture-dependent economies, many islands in the Pacific and Caribbean have seen profound shifts away from export-based plantation agriculture as the political economy changed (Rhiney, 2016). In Hawaiʻi's case, this has resulted in large swaths of unmanaged, fallow, fire-prone land, and a nascent diversified agricultural sector to supply local food.

Freshwater on islands is an increasingly threatened resource, prone to overuse and inadequate management (Gheuens et al., 2019). Throughout islands, climate change is increasingly impacting water, causing droughts, intense precipitation events, and sea level rise that contaminates groundwater (Frazier et al., 2023). Other threats to water security include natural disasters, fire, population growth, development, pollution, and invasive species.

Water scarcity has led to significant and increasing conflicts between users (Levy & Sidel, 2011). Many small islands have high levels of freshwater inequality (Anthonj et al., 2020). In Hawaii, conflict over water has been fierce for over a century, as diversion of surface water and overwithdrawal of groundwater has left local farmers and Indigenous peoples without their customary rights, and, more currently, many areas prone to fire risk (Chang, 2023; Scheuer, 2021).

Indigenous resource management institutions acknowedged the connectivity between mountains and coasts, land and water, and people and nature (K. Sproat, 2011). In Hawaiʻi, the ahupuaʻa was a traditional land division unit generally following watershed boundaries that allowed for holistic management to achieve food and water security (Winter et al., 2018). Modern institutions fractured these traditional institutions, placing mandates for water source conservation, supply, and quality under different, centralized government institutions (Silva, 2004). In Hawaiʻi, for instance, the State Commission on Water Resource Management has a mandate to protect ground and surface water resources; the Department of Health promulgates and enforces regulations, standards, and policies; engineers at the State Department of Land and Natural Resources develop water projects; the Department of Agriculture is in charge of overseeing water use, supply, and irrigation systems on agricultural lands. Meanwhile, county-level land use commissions develop long range land use plans; and county boards of water supply and waste management treat and deliver water to customers and remove sewage; and county utilities manage stormwater.

Improving water security on islands requires multi-faceted policy to address the environmental, political, economic, and social drivers of insecurity. In Hawaiʻi, water security is at the forefront of policy discussions. Numerous strategies and plans exist to meet state and county goals to decrease consumption, increase supply, prevent contamination, improve management of watersheds, stormwater, and wastewater, and adapt to climate change. These efforts are underpinned by a detailed state water code, which is based on Hawaiʻi's state constitution that declares the state's "obligation to protect, control, and regulate the use of Hawaii's waters for the benefit of its people" (Article 6 §7). A key document guiding water security efforts in the state calls for consistent metrics and collaboration across agencies, a dedicated entity with a data clearing house, and tracking progress towards meeting goals (Hawaii Freshwater Initiative, 2016). To-date, these do not exist, but accounting could fill these needs.

Water accounts for the island of Oʻahu (i.e., the City and County of Honolulu)

Water accounts track water's value to society. Water accounting organizes and presents information on the physical volume of water as well as the economic aspects of water supply and use (Vardon et al., 2012). Water accounts start by tracking water's physical supply and use from different sources (e.g., surface water, groundwater, oceans), disaggregated by different user types (including domestic use). It then catalogs the quantity and, in some cases, quality of return flows to the environment, and water trade (if any) with neighboring countries or states. Advanced water accounts can also include physical and monetary asset values for water bodies like aquifers. Water flows *between* economic sectors (e.g., municipal, agricultural, energy production, industry, environment) are also shown – illustrating how water adds value to different economic sectors. Water accounts show recent historical trends in water availability, use, and quality, and their impacts on the economy, allowing decision makers to more proactively evaluate emerging threats to water security. The SEEA Water framework includes five types of accounts: 1) water assets, or the stocks of water at the beginning of an accounting period, 2) physical supply and use tables (PSUTs), or water use by industry throughout an accounting period, 3) water quality, 4) water productivity, or the GDP each sector produces relative to their water used, and 5) water emissions, which accounts for the supply of pollutants added to wastewater and the treatment thereof (United Nations, 2012).

We developed pilot water supply and use accounts (PSUTs) for islands of Oʻahu and Maui, which correspond, in governance terms, to the City and County of Honolulu, and the most populated island within the county of Maui, respectively. (Maui county also includes the islands of Lānaʻi, Molokaʻi, and Kahoʻolawe.) The PSUTs covered the period 2010-2017 and explored the potential for water quality, emissions, and asset accounts based on the UN SEEA water framework. Oʻahu was chosen as it is the most populous island with both rural and urban areas, a relatively diverse economy, and high reliance on groundwater, while Maui is more rural, economically dependent on tourism and agriculture, highly reliant on surface water, with intense water conflict issues.

This project entailed working with a team of researchers who collected data from disparate sources (27 data sources for Oʻahu), iterating to address discrepancies, and triangulating to fill gaps. Multiple water experts provided input into the process and feedback on the product, including boards of water supply, the state Department of Agriculture, and citizen groups and NGOs working in the water space. In Hawaiʻi, as in many jurisdictions, water data are collected and housed across various agencies, limiting the capacity for informed, system-scale decision-making (Simonovic, 2009). Data are collected and used by agencies such as county boards of water supply (BWS), the state commission of water resource management (CWMR), federal agencies such as the United States Geological Survey (USGS), private entities including agricultural producers and wastewater treatment plants, and academic institutions; yet, there is no central repository for these data. Data are often concealed in PDF reports, rather than accessibly tabulated in spreadsheet format. Disaggregated and inaccessible data result in inconsistent data categories, units, and definitions across agencies, and may hinder the efficiency and efficacy of water management in Hawaiʻi.

Draft water accounts were presented to collaborating agencies in early 2019. In early 2020, revised tables were publicly presented at the Pacific Water Conference in Honolulu, HI, and again at a stakeholder workshop convened by the Water Resources Research Center. Finally, a workshop was convened in April, 2020 to discuss the final tables with data managers at cooperating agencies, at the end of which a short survey was conducted to gather feedback.

Oʻahu physical supply and use tables

For concision, only the results of the PSUTs for the island of Oʻahu are included here, as the main take-aways for the SEEA method revisions are similar across contexts.

The island of O‘ahu, which has an area of 1545 km^2, is home to one million residents and is visited by over half a million tourists a month. Major economic sectors include tourism, real estate, the government, and the US military.

Over 1,729 million gallons of water cycled through O‘ahu’s economy each day in 2017. This was roughly equivalent to 172 gallons per person per day, and comparable to our average across the accounting years (2010 – 2017) of 1,929 mgd (SD: ± 177 mgd). Overall, the largest abstractor of fresh water on O‘ahu was consistently the public supplier (Board of Water Supply) (142 mgd); of which the vast majority (90%; 118 mgd) went to domestic users (households and non-residential uses, including hotels and resorts). The thermoelectric sector was the largest water user (Figure 1), but the sector used predominantly ocean water.

O‘ahu is highly dependent on non-saline groundwater for supply of drinking water (189 mgd non-saline – i.e., fresh and brackish - groundwater abstractions compared to 16 mgd fresh surface water; Figure 1). This dependency on non-saline groundwater for drinking water is a dominant narrative in Hawai‘i.

In contrast to drinking water, surface water is the primary source for non-drinking water uses. Surface water enters the account two ways: as direct abstractions from surface water bodies, i.e., lakes or streams, and as passive use, i.e., rainfed systems. If we count dependence on rainfall, comprised in our accounts predominantly of rain-fed agriculture (i.e., Agriculture), then O‘ahu is nearly equally reliant on surface water as it is on groundwater. For example, soil water (i.e., the water from mist and rainfall that percolates through soil and is available to plants) constitutes the majority (144 mgd) of total surface water abstractions (160 mgd), which is close to the level of fresh groundwater abstraction (189 mgd). In fact, the dependence on surface water is likely higher than our estimates suggest, as deficiencies in surface water data forced us to omit unknown quantities of direct surface water abstractions. Additionally, our estimations of rainfall use do not include anything other than soil water use for agriculture, livestock, aquaculture, and irrigation sectors. Moreover, rainwater catchments, which are also important in domestic and drinking water, especially in the more rural areas, are also omitted as we could not locate reliable data on catchments.

One of the powers of the PSUT format is its ability to portray information on both abstractions and returns. In many water management practices, data for the second half of the economy-water cycle (returns to the environment, post-use) are sparse. Each sector returns small amounts to the environment, while some sectors return flow to sewage treatment facilities (Table 1). A small amount (11 mgd) of treated wastewater (total 140 mgd) is reused, mainly for irrigation of golf courses and parks, while most is disposed of in the ocean (Figure 1; Table 2). About 23% of water is evapotranspired, included in products, or otherwise lost from the system. Lastly, economic users return nearly a quarter (43 mgd) of non-saline wastewater directly to the environment without prior treatment, while nearly three quarters (140 mgd) are treated at wastewater treatment plants before being reused (11 mgd) or returned to the environment (Table 1).

Through this process we identified six key data discrepancies and challenges. We shared these with over a dozen stakeholders from both public and private water agencies and organizations via a stakeholder workshop and survey in April 2020; their feedback is summarized in Table 3.

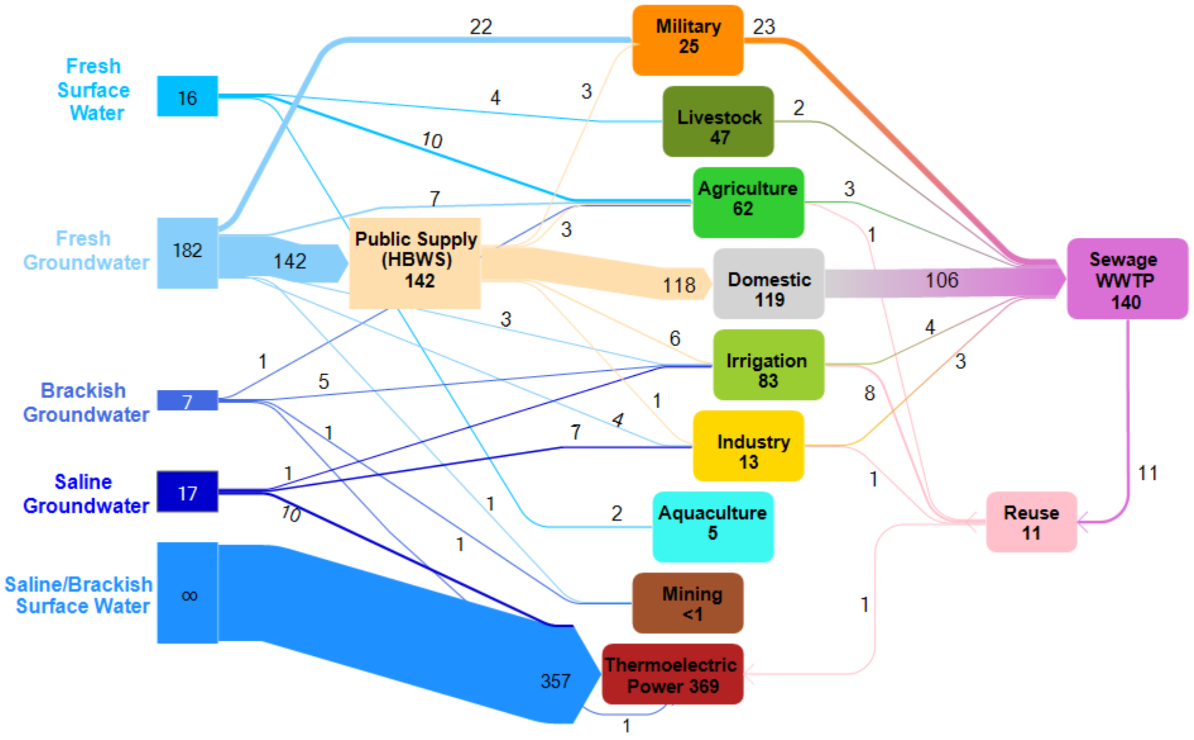

Figure 1. Water Use on O'ahu 2017. Water sources (left side) and use by economic sectors (middle-right). All units in mgd. Flows <0.5 mgd are not included in the diagram. Above graphic does not include rainfall or soil water estimates, losses, evaporation, evapotranspiration, consumption in product, or direct returns from sectors to the environment.

Table 1. PSUT ***Supply Table*** *2017 O’ahu. All values in MGD (million gallons per day).* ***Values*** *in bold/italics are measured data. All other values are data based on assumptions or modeling.*

	Public Supply	**Domestic**	**Aquaculture**	**Livestock**	**Agriculture**	**Irrigation**	**Industries**	**Mining**	**Thermoelectric Power**	**Military**	**Sewage**	**Environment**	**Total**
Within the environment													
Surface withdrawal													
Soil water												144	144
Fresh water												16	16
Saline water												357	357
Groundwater withdrawal													
Fresh water												182	182
Brackish water												7	7
Saline water												17	17
Within the economy													
Public supply	***132***												132
Reuse											11		11
Losses	***11***	5	0	0	0	0	1	0	0	0.6	0		17
Wastewater													
Returns to Sewage		106	0	2	3	4	2	0	<1	23.1	<1		140
Direct returns to Environment		5	3	16	17	20	0	<1	110	0.6	129		301
Consumption													
Evaporation/AET/ Inclusion in products	0	4	1	29	42	59	10	<1	258	0.8	0		404
Total	143	119	4	47	62	84	13	<1	369	25	140	723	1729

Table 2. PSUT ***Use Table*** *2017 O'ahu. All values in MGD (million gallons per day).* ***Values*** *in bold/italics are measured data. All other values are data based on assumptions or modeling.*

	Public Supply	**Domestic**	**Aquaculture**	**Livestock**	**Agriculture**	**Irrigation**	**Industries**	**Mining**	**Thermoelectric Power**	**Military**	**Sewage**	**Environment**	**Total**
Within the environment													
Surface withdrawal													
Soil water			<1	42	39	62							144
Fresh water		0	2	4	10	0	0	0	0	0			16
Saline water			0				0	0	357	0			357
Groundwater withdrawal													
Fresh water	***143***	***<1***	***2***	***<1***	***7***	***3***	***4***	***<1***	***<1***	***22***			182
Brackish water	0	***0***	***<1***	***0***	***<1***	***5***	***0***	***<1***		***0***			7
Saline water		***0***	0	0	***0***	***<1***	***7***	***0***	***10***	***0***			17
Within the economy													
Public supply		***118***	0	0	***3***	***6***	***1***	0		***3***			132
Reuse	0				1	8	1		1	0	<1		11
Losses												17	17
Wastewaters													
Returns to Sewage											140		140
Direct returns to Environment												301	301
Consumption													
Evaporation/AET/ Inclusion in products												404	404
Total	143	119	4	47	62	84	13	<1	369	25	140	722	1729

Table 3. Stakeholder feedback related to accounting data issues encountered

	Problem	Solution	Perspectives
#1	Water data are fractured across agencies and organizations, with many data stored in PDFs rather than spreadsheets, making analytics and automation challenging.	**A central data repository for public and private water data groups**	Over 72% of stakeholder respondents agreed or strongly agreed that it would be beneficial to create a data platform with standardized units, thresholds, and categories to share and unify data cross public, private, and academic water partners. The need for a central data repository is coherent with Hawaiʻi Freshwater Council's recommendation to establish an entity that serves as a water data clearinghouse. When asked, on a scale of 1 (perfect framework) – 7 (not the right framework at all), "How well does the SEEA natural capital accounting framework serve this need for a collective unified data tool?" two-thirds of respondents ranked the framework as a 4, and roughly one-third ranked it as a 2. When stakeholders were surveyed on where they would imagine the State data framework being institutionalized, the results were spread across state agencies. Many agencies voiced that this did not fall within their mission statement. In summary, there is impetus and consensus on the issues, but a lack of central capacity to operationalize and take ownership of such a repository, as well as the exact framework to advance.
#2	Categories, metrics, and thresholds are incoherent across water agencies. *	**Collaboration among HBWS, USGS, and CWRM over comparable categories and metrics**	The need for consistent metrics and better data parallels was identified by Hawaiʻi's Freshwater Council in 2016. Stakeholders voiced similar

			frustrations with the discrepancies across agencies, but each had reasons for maintaining their current method. USGS does not have leeway to move away from national standards; CWRM bases categories on legal code definitions; and, BWS defines their categories to help best shape their rate schedule. Because CWRM had the most detailed and advanced categorization, it may be most effective for other agencies to additionally report their data as they best can to be compatible with CWRM categorization; an automated central system could be designed to accomplish this.
#3	Current management tools predominantly reflect aquifer water abstractions, and neglect non-aquifer water uses. Understanding human reliance on rainfall and AET patterns help the County better understand its full water demand and plan for impacts of a changing climate.	**Utilization by government agencies of geospatial data and modeling to better account for rainfall, actual evapotranspiration (AET), and land-cover.**	Stakeholders identified the State Office of Planning as the central state data house for GIS, if not within academic institutions (i.e. the University of Hawaiʻi system). USGS voiced an interest in annual land-cover mapping, however questioned their capacity. No other agency seemed to feel that this fell under their mission.
#4	Wastewater treatment plants are required to have an effluent flow meter installed; however, they are not required to report out; thus, there is no data base of historical wastewater treatment plant effluent or influent flows. One would have to individually acquire this from the approximately 250 plants. This is a capacity issue not a technical issue.	**A central entity that obtains wastewater flow data (influent and effluent) from wastewater treatment plants statewide, which are legally required to gauge influent and maintain the data for two years**	Department of Health Wastewater Branch (DOH-WWB) shared that it does not have the bandwidth or resources to obtain flow data from the approximately 250 treatment plants statewide. A third party academic or non-profit support group could pilot the collection of this data. Eventually, this reporting and tabulation process could be automated and stored in a central repository.
#5	Current data does not sufficiently reflect surface water abstractions and user dependence. Most of the surface water information the commission has is based on 30-yr old registrations.	**Increased surface water data collection**	CWRM has been the primary agency to take initiative on this topic and intends to expand collection methods by adding more water gauges, building out their service areas, and designing a survey or annual registration process

			to better understand the landscape of surface water extractions.
#6	A localized, bottom-up approach to the SEEA-W process is meticulous, disincentivizing annual account creation and maintenance.	**Automation of the local SEEA water accounts**	A software such as Power Bi could automate the accounting process and facilitate continued and consistent accounting. This automation could benefit many of the other recommendations above; however, there is still the question of where to house such compilations. Moreover, the ability to pull information and automate the accounting process requires a level of initial synthesis and coordination. Previous solutions such as creating a central data repository, would provide the ability to query information directly from websites, which would be key to an automated account.

[*] **Salinity units and thresholds:** The different agencies use different salinity definitions. USGS defines freshwater as having <1,000 mg/l of dissolved solids. Everything else, >1,000 mg/l, is considered saline by USGS. Conversely, CWRM data includes fresh, brackish, and saline water, which they define using chlorides concentrations from 0 - 250, 251 - 16,999, and >16,999 mg/l chlorides respectively. Lastly, HBWS prefers to distribute water containing less than 160 ppm (equivalent to 160 mg/l) of chloride ions, but will consider higher levels where it is appropriate to blend fresh and brackish. Not only do the thresholds vary across agencies, their units do as well, making accounting challenging.

User categories: USGS combines Irrigation and Agriculture into one category, which they call "Irrigation." Alternatively, USGS disaggregates Livestock and Aquaculture into their own categories. HBWS (Public Supply) has separate categories for Irrigation and Agriculture. HBWS does not send water to livestock or aquaculture, so they are not included in their agriculture category. CWRM has the most advanced category disaggregation, subcategorizing irrigation, agriculture, livestock, and aquaculture. We understand part of the challenge in synthesizing categories is that CWRM defines user by well owner and HBWS defines user by metered gauge owner, but we encourage an attempt at uniformity for the sake of the accounting process.

Lessons relevant to SEEA revisions

A number of key lessons for the SEEA revision process emerge from having applied the water accounting framework to the islands. To be useful for freshwater planning and policy in an era of increasing scarcity and uncertainty, accounts need to be able to inform decisions about source protection, water allocation and pricing, and water conservation and reuse.

Water accounts need to fit the scale of the decision-making context

Topic issues covered:

- *Primary: A4 (How SEEA CF can be made spatially explicit); D2 (Inclusion of water quality accounts)*
- *Secondary: A7 (Extension to social domain)*

Reporting water accounts annually at the whole island scale is insufficient to inform most local water management decisions. Water is useful when it is available in sufficient quantity where and when it is needed while being of adequate quality for its intended use. To add value to water managers, accounts need to synthesize information about water supply, use, and quality spatially, at spatial and temporal scales that match the eco-hydrologic and socio-economic systems. Such detailed and coordinated information will be useful for planning and water management (including response to crises, climate adaptation, and equity assessments), and also aid in accurate water valuation, which can support water pricing and putting water to its societally most productive use.

The case of Oʻahu illustrates the need for concurrent reporting:

- Groundwater abstraction in Oʻahu derives from specific aquifers, some more confined, exploited, or at risk (e.g., of salt water intrusion, dought, contamination) than others. Similarly, surface water withdrawal may derive from streams with different (seasonal) flows, legal in-stream flow requirements, habitat, stressors, quality, and claims (traditional farming, etc.). Managers need information on source location and quality and timing of withdrawals.
- Aquifer and watershed extents do not correspond, so ecosystem accounting units may include parts of each. Integrated water resource management requires these systems to be considered holistically, including connections between surface and groundwater. Careful attention should be paid to delineation of accounting units such that they facilitate both local and system-scale management.
- Human-caused diversions (irrigation ditches) transport large volumes of water great distances, implying that the water abstraction may have derived from distant locations. (A parallel complexity relates to lava tubes, which are natural tunnels that can shunt water long distances, obscuring the origin of the water.)

A similar logic applies to losses and returns to the environment. The quality of the water and location of the loss/return will determine whether the water is available for reuse and potential risks to receiving environments and communities. Moreover, it is important to note that returns to the environment are not static. The case of the Lāhaina wastewater treatment injection well illustrates this point. Treated wastewater injected into the groundwater inland rapidly flows to the nearshore environment, where it imperils the health of the coral reef.

In summary, at a minimum, supply and loss/return data should be geolocated (at least to aquifer and watershed) and temporally tagged. This would enable cross referencing with quality data and ecosystem types (to link to the SEEA) and socio-economic data. Ideally, water quality information would be simultaneously reported with abstraction and returns, as quality thresholds will be more important than average conditions. Unfortunately, islands have historically been under-served by data providing agencies. For Oʻahuʻs accounts, for instance, the main data gaps for our pilot accounts were: location and levels of aquifers, surface water flow and withdrawals, evapotranspiration from and location of specific land uses (with attention to crops grown in tropical islands), public water supply system losses, emissions, water quality, and rainwater catchments. We also had difficulty gathering data from the military. These realities imply that, while islands are small, they likely require more, not less resolution, and therefore data.

Should managed aquifers be considered a produced asset

Topic issues covered:

- *Primary: D4 (Consideration of water as a produced asset)*
- *Secondary: A4 (How SEEA CF can be made spatially explicit); A8 (Explicity linking/integrating environmental activity accounts, asset accounts, and flow accounts); B9 (Own account production); B12 (Borderline cases);*

The potential of treating reservoirs as produced assets has been discussed by the SEEA community for over a decade (and is the topic of an issue paper led by Michael Vardon this year). Consistent with that logic, the question arises whether highly managed aquifers could also be considered as produced assets. Doing so would enhance the policy relevance of the accounts for island water management, providing information critical to fulfilling the public trust mandate of the state, while more closely aligning with Indigenous worldviews of water.

Water asset accounts measure stocks of water, and include two components, (1) produced assets (used for abstraction, mobilization, and treatment of water), and (2) water resources (SEEA-Water para 2.37). Produced assets are defined in the SNA as “non-financial assets that have come into existence as outputs from production processes that fall within the production boundary of the SNA” (SNA para. 10.9). Produced assets related to water, such as infrastructure to abstract and treat water, are generally included within the SNA asset boundary, and therefore compiled in aggregate in the conventional accounts. Water resource asset accounts describe the volume of water resources in various asset categories and all the changes that are due to natural and human activities (SEEA Water para 2.39). Water resources that are “used for extraction to the extent that their scarcity leads to the enforcement of ownership or use rights; market valuation and some measure of economic control” fall in the SNA asset boundary (SEEA Water para 2.41).

Aquifers are the main source of drinking water for most islands, and therefore of utmost policy concern. Clearly aquifers are an asset, defined by the SNA para 10.8 as “a store of value representing a benefit of series of benefits accruing to the economic owner by holding or using the entity over a period of time. It is a means of carrying forward value from one accounting period to another.” The relevant question is whether aquifers can be considred produced assets per SNA para 10.9.

Land in small islands is scarce, and geology often precludes surface impoundment of water. Building on millennia of Indigenous knowledge and practices, many islands spend considerable resources and incur high opportunity costs to protect watersheds and underlying aquifers. In Hawaiʻi, watershed management cooperatives steward upland ecosystems, while land-use zoning prohibits development of highly valuable land important for aquifer recharge. Aquifer levels and quality are carefully monitored, and abstraction controlled. These efforts arguably fall within the definition of “production” as “an activity, carried out under the responsibility, control, and management of an institutional unit, that uses inputs of labour, capital, and goods and services to produce outputs of goods and services" (SNA para 6.2). The asset itself (i.e., the water stored in the aquifer) would be less without human intervention in the form of environmental activities, and therefore could fall within the SNA definition of produced assets (para 10.9). Moreover, it qualifies as an inventory under SNA para 10.12, "produced assets that consist of goods and services, which came into existence in the current or in an earlier period, and that are held for sale, use in production ar other use at a later date".

Treating managed aquifers as an asset more accurately reflects economic and environmental activities needed to manage the aquifer. Adding aquifers to the accounting inventory, and any abstractions, injections, and losses, would enable tracking and valuation of overwithdrawal and contamination, and aid in valuation for water rights and damages, all of which are pressing policy issues.

Aquifer accounts could have helped in the response to a recent crisis on Oʻahu. Jet fuel leaked from the Red Hill Underground Fuel Storage Facility, poisoning residents and causing long-term water shortages due to the indefinite shutdown of many water sources. Had detailed accounts been available, including water quality information, the leak may have been detected sooner, and affected users could have been identified and informed. Estimating the damages associated with the contamination could also be informed by the accounts.

Another tense issue in the Hawaiian Islands relates to privitization of groundwater. Private developers are often granted withdrawal permits, despite clear externalities of the use, in part due to the regulatory agency's lack of sufficient data upon which to base decisions. The balance of power lies with the developers (many of which have roots in the former plantation congomerates). These water withdrawals often over-exploit aquifers and diminish surface water flows, negatively impacting stream ecosystems, traditional farming, ranching, and recreational uses, among others. Detailed accounts could provide agencies with the information they need to optimize withdrawal permits with other, competing uses.

Considering managed aquifers as produced assets would also serve to link the SEEA-CF (and Water) to the SEEA EA, which explicitly considers water inflitration service, and values assets as the future stream of benefits, and wealth accounting.

Another produced asset is important to islanders, yet currently omitted from the accounts. Many islanders rely on household water catchments. In atolls, catchments are the primary method of storing freshwater and rainwater harvesting is critical to freshwater supply across all islands, particularly in remote areas (Wallace and Bailey; Quigley; Anthonj). People reliant on rainwater harvesting are vulnerable to droughts and face increasing uncertainty due to climate change. Including rainwater catchment as produced assets would expand the utility of the accounts for islands, and could play an important role in analyzing vulnerabilities and ensuring freshwater equity.

Clarity, granularity, and consistency of information

Topic issues covered:

- *Primary: A4 (How SEEA CF can be made spatially explicit); B7 (Inclusion of residual flows to ecosystem type)*
- *Secondary: A6 (Introduction of thematic accounts and strengthening the link to policy); B2 (Clarifying treatment of losses)*

As noted in the response from our stakeholders, many did not think the accounts (as currently constructed) were useful for fulfilling their mandates or achieving state water goals.

One clear improvement (beyond more spatial resolution) would be to break down the “Domestic user” category into finer units. This would facilitate analysis of the distribution of benefits, and creation of thematic accounts (e.g., tourism). The USGS/state “Domestic” use category lumps indoor and outdoor household and non-residential use. Hotels and resorts are grouped into the latter, which precludes an analysis of the water productivity and impacts of the tourism sector, for instance.

Another improvement would be to differentiate the “Returns to Environment” use. This use category includes many avenues for water to reenter the water cycle from the economic process: loss in transit between extraction and use, wastewater (return to sewage or direct returns to the environment directly into surface or groundwater), and evapotranspiration or water consumed during economic use. These returns can be quite important for future water security, and pose significant risk to receiving environments. Which type of return it is, where that occurs, and the water quality are especially important to know. Adding specifics to the accounting table could help guide source protection, recharge estimates, circular economy intiatives, and water conservation efforts.

Two cases illustrate the utility of better resolution in the returns to environment in our water scarce islands. First, the vast majority of wastewater, treated though oxidation, filtration, and disinfection to be safe for human contact, is returned to the environment; less than 8% of the treated water is reused on Oʻahu. Many stakeholders were surprised by the small reuse percentage, and some environmental groups requested more information about the destination of the returns (on Oʻahu, disposal is through an ocean outfall; on Maui, some is injected into the groundwater). In the case of the Lāhaina wastewater injection well, which is located close to fragile coral reef systems and extensive resort properties, improved resolution could help guide ongoing efforts to use reclaimed water for landscaping and post-fire recovery, identifying potential users and facilitating assessment of potential environmental impacts.

A third improvement would be to standardize categories and definitions across agencies. For instance, the USGS and state agencies do not use the same use categories, and each has a different threshold for salinity. Such discrepancies limit synthesis of water data across data sources.

Water for non-market benefits

Topic issues covered:

- *Primary: D7 (Valuation of water)*

In addition to marketed goods and services, water is critical to non-market benefits that are currently ignored by the CF accounts. The accounts, by design, focus on the economic contribution of water, and value water at its exchange price. As such, the accounts focus on extractive uses of water (e.g., water for domestic, industrial, and agricultural use). In principle, the water accounts can help allocate water to its most economically productive use. Valuation of water has long perplexed economists, however, as the price of water is seldom reflective of its market value. Deriving the exchange value of water, required for the SEEA, is not straightforward.

The SEEA-CF accounts ignore water supply important for non-market benefits, such as in-stream flow for recreation, subsistence agriculture, and cultural practices. Water managers, however, are faced with balancing competing uses of water, and require information on all benefits of water. Valuing these benefits can help make broader societal prioritization and trade-off decisions, but only if all benefits can be accurately defined, quantified, and evaluated. Most non-market uses of water have no market prices, and many non-market valuation methods do not comply with the strict SNA exchange value concept. Moreover, water has many values, depending upon its framing as a human right, an entity in its own right, or an economic good. In Hawaiʻi, a common phrase is "water is life", and people acknowledge a reciprocal relationship with water and the ecosystems that supply it.

The concern is that if the values of water cannot monetized, that the benefits that can be monetized will dominate the decision calculus. Some initial steps to ensure the greatest societal benefit from the use of water could be for the accounts to provide a breakdown of ecosystem service water uses to serve as an explicit tie from the water account to aquatic ecosystem accounts. In the absence of agreement on valuation methods, information on physical flows to these benefits could serve the need in decision making. Finally, with complex water decisions, alternative valuation approaches and decision tools drawing on information within the SEEA should be explored and explained in the accounts. Others have suggested creating parallel accounts reflective of welfare value to present alongside water accounts that are based on the SNA. Other efforts to balance competing objectives and value systems for resources have focused on deliberative valuation and multi-criteria decision analysis.

Conclusions

Managing and accounting for water on islands requires understanding the particular context of these systems, including the importance of place and histories of traditional management. Our bottom-up data compilation approach, while laborious, had benefits in the sense that it created interest and ownership of these data and acknowledgement of the need for coordination amidst multiple local water stakeholders. Reviewing the pilot accounts alongside stakeholders, we identified numerous areas for improvement to enhance the local policy relevance of the accounts. Water accounts need to be sensitive to the aquifer and watershed geography of islands, pinpointing supply and use to these features. On islands, aquifers are the principal water storage device, and their intensive management could qualify them as produced assets. Economic users need to be further disaggregated to facilitate analyses and distinguish economic sectors, as do returns to the environment to better reveal environmental impacts and reuse opportunities. Finally, decisions related to water need to reflect the multiple values of water, otherwise economic production will be prioritized at the expense of other uses.

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