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Improving data quality, applicability and transparency of national water accounts – A case study for Finland

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ABSTRACT

This paper introduces a novel procedure for the compilation of highly disaggregated water accounts by using Finland as a case example. The procedure is based on combining the use of existing standard economic statistics and other registers and databases with a dataset on water supply and use collected in the present study. As an outcome, water supply and use accounts are presented for 195 industries in the Finnish economy in 2010. The water accounts presented are based primarily on actual water supply and use rates and distinguish between various raw water sources and uses: groundwater, fresh surface, brackish water self-abstracted for own use, and mains-water supply and use. Separate accounts for cooling water are presented. The paper covers flow accounts from the environment to the economy and within the economy excluding all return flows. Data coverage issues and potential sources of error are reported in detail and discussed together with the applicability of the procedure in other countries. Implications for the System of Economic-Environmental Accounting for Water (SEEA-Water) framework are assessed.

1. Introduction

Insufficient supply of clean fresh water and water pollution are becoming the most serious problems humanity will be facing in the forthcoming years and decades: World Economy Forum has identified water-related risks, together with climate change and loss of biodiversity, among the risks with the highest impact on human societies in their recent analyses [1,2]. In response to this anticipated adverse development, water-related issues have gained increasing attention in scientific communities and in international organizations.

Subsequently, methodologies for water accounting have been under development since the 1980s. In 2012, the United Nations published the latest version of their System of Environmental-Economic Accounting for Water (SEEA-Water) [3]. It provides a framework under which the flow of water from the environment to the economy, within the economy, and back to the environment can be organized in a systematic manner compatible with the System of National Accounts (SNA) [4]. This satellite system of the SNA also presents principles under which data on water stocks or assets, water reuse, and various financial items related to water supply and sanitation can be organized. To date, water accounting has been carried out, for instance, in Australia [5], Canada [6], Denmark [7], the Netherlands [8,9], Spain [10] and Sweden [11]. In all of these cases, national statistical offices have been responsible for the accounting. Typically, up to 30 industries of the economy are covered in these accounts. Recently, however, Graveland et al. [9] reported water supply and use data for about 130 industries in the Netherlands. In terms of methodology, the Australian [5] and the Dutch [9] water accounts have been compiled according to the SEEA-Water framework. Spain [10] and, previously, the Netherlands

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[8], applied the National Accounting Matrix including Water Accounts (NAMWA) [12]. Despite the continual progress in the field of water accounting, the accounting frameworks and their outcomes have, however, been criticized for falling far short of meeting the needs of end users and thus gaining little interest or societal impact [13].

Other approaches intended for the quantification and evaluation of water use, consumption and pollution are various "water footprint" methodologies. Hoekstra et al. [14] published a manual on the assessment of these water footprints in which they make a distinction between blue water (i.e. volume of groundwater and surface water consumed), green water (i.e. volume of water transpired by cultivated plants) and grey water (i.e. volume of polluted water). Based on their work, estimates for water consumption covering both domestic water and water embedded in imported commodities have been calculated for countries and regional entities such as the European Union [15], France [16], Tunisia [17], Brazil [18] and China [19]. These calculations, however, are based on modeled data instead of actual documented rates (m^3/a) of water abstraction, use and consumption.

Similarly, water-use rates for nations can be calculated by using environmentally extended input-output (EE-IO) models that are amended with water withdrawal or consumption data [20–22]. EE-IO models can be divided into national models such as the EE-IO model of the Finnish economy (ENVIMAT) [23] and multiregional (EE-MRIO) models that typically cover countries responsible for over 90% of the world's gross domestic product (for a review, see Ref. [21]). Data on water use is, however, often missing from such models. This is the case also for the ENVIMAT model. An example of an EE-MRIO model that does contain data for water use is EXIOBASE [22]. It covers water use for 43 countries and 5 rest-of-the-world regions, 163 industries and 200 products, as well as water-withdrawal and water-consumption data for roughly 80 and 100 industries, respectively, with an emphasis on agricultural products. By using EXIOBASE, Tukker et al. [24] calculated estimates on the water-withdrawal and water-consumption rates for 48 nations or regions. The model has also been used to provide estimates on national water-consumption rates, including water embedded in imported commodities [19,25]. Like in the water footprint manual [14], water data in EE-MRIO models are – if available – based on modeling and are thus prone to inconsistencies and inaccuracies of an unknown level [26,27]. To improve the reliability and transparency of water-sustainability studies, high-quality data on water use suitable for EE-IO models is thus urgently needed.

A major advantage of the EE-IO models is that they are closely linked to standard economic and environmental accounting frameworks like the SNA. That said, water accounts following the structure of these frameworks can be used as input for EE-IO models. Unfortunately, the data provided by the national water accounts described earlier in this section are either too aggregated or too incomplete in sectoral coverage to meet the needs of the EE-IO models [28]. In the case of the ENVIMAT model, for example, water accounts with data for 150 industries are required [23]. Aggregation of industries to create a better fit for available data, however, is not a methodologically feasible option because inaccuracies resulting from aggregation over industries are one of the major drawbacks of the EE-IO modeling [29,30]. Subsequently, the remaining option is to provide highly disaggregated data on water use that are based on actual water-use rates. The application of such water accounts is not limited to EE-IO modeling and sustainability studies. By contrast, they are highly relevant in addressing economic analyses in the context of the E.U. Water Framework Directive (WFD) [31].

This paper introduces a procedure for the compilation of highly disaggregated water accounts and for the first time, to our knowledge – reports and discusses the data coverage issues and potential sources of error relevant for the assessment of the accuracy of the accounts presented. In addition to the detailed description of the procedure developed, we present water supply and use data for 195 industries in the Finnish economy. The accounts cover water-abstraction rates both from the environment to the economy and within the economy (mains water) in 2010 but exclude the return flows. To further broaden the applicability of the accounts, the paper reports separate supply and use tables for ground water, surface water, brackish water and mains water. Furthermore, distinct accounts for cooling water are reported. This paper responds to several essential shortcomings prevailing in the field of water accounting. It presents a procedure to produce high-quality water accounts with the high level of disaggregation called for by the SEEA-Water documentation [3]. The accounts are primarily based on actual water-use rates rather than modeling. The procedure developed also allows a transparent assessment and documentation of any data-quality issues encountered in the dataset collected. International applicability of the procedure and the implications of the current work on the SEEA-Water framework are also discussed.

2. Material and methods

2.1. Methodological requirements

In this chapter, we describe our procedure for the compilation of highly disaggregated water accounts with a systematic and transparent data quality reporting. We begin, however, by describing the boundary conditions initially set for the development work.

First, to guarantee further applicability, the accounts must meet the requirements of the ENVIMAT model by providing water-use data for the 150 industries included in that model. In ENVIMAT, the most recent economic and environmental data were collected for 2010; hence, water accounts need to be compiled for that year as well. ENVIMAT is compatible with the statistical classification of economic activities in the European Community (NACE) used by the European System of Accounts (ESA) [32] and described in NACE Revision 2 by the European Commission [33]. This classification distinguishes the quality of data on economic activities according to digit-levels: a higher number of digits indicates a higher level of detail. Since in ENVIMAT, 2 or 3 digits are generally used – as indicated in Appendix A1 – data collection should be performed at this minimum level of sectoral detail. Some industries, however, have very diverse subindustries in terms of their water use. For instance, manufacture of other food products (NACE code 108) contains the subindustries manufacture of sugar (1081) and processing of tea and coffee (1083), which have vastly different water-use intensities. In such cases, a goal was set to collect water supply and use data on the 4- or even 5-digit level of the ESA. This way, a major source of uncertainty and error in the water accounts can be controlled. Other subindustries that have specific and relevant water use were identified by analyzing the *Regional Statistics on Entrepreneurial Activity* [34] that distinguish subindustries down to the levels of 4 or 5 digits and contain nearly 1100 industries and subindustries. The individual industries, 195 in total, for which water-use data were collected are presented in Appendix A1. Individual industries characterized by low total revenue were excluded from the data collection. Combined, these excluded industries represent approximately 0.07% of the revenue generated by all industries in the dataset [34].

Second, to guarantee that the water accounts produced could potentially be applied for international reporting and development work, we set a goal to meet the most relevant requirements of the SEEA-Water framework [3]. The basic idea of the SEEA-Water is that water flows – from the environment to the economy, within the economy and from the economy to the environment – are accounted for in a systematic way. Our study followed that basic principle but was limited to water flows from the environment to the economy and, within the economy, to the supply and use of mains water. Hence, return flows within the economy – that is, waste waters introduced to the sewerage (NACE 37) – and from the economy to the environment were excluded and remain a matter of further study. However, since we also wanted to critically evaluate the feasibility and applicability of the SEEA-Water framework, exceptions to its application were made where justified. SEEA-Water framework uses International Standard Industrial Classification (ISIC) of the United Nations [35] while Statistics Finland uses NACE classification, which is derived from ISIC classification. Some for the industries present in NACE and used in this study are missing from the ISIC classification. The correspondence of the industries in the two classification systems can be found in Annex I in the ESA documentation [32].

Third, we agreed that the procedure we developed should enable a systematic way of compiling the accounts so that the quality of the data could be reliably estimated and reported. It should primarily take advantage of existing statistical data and other registers and databases with high quality data and continual updating. By using statistics commonly produced by national statistical offices, the procedure developed here would also benefit the methodological development of other EU countries [36] or global territories. This way, the study would also make a significant contribution to the development of data-quality frameworks in the context of water accounts: Frameworks that are currently missing and are explicitly called for by the SEEA-Water documentation [3].

2.2. Description of the developed procedure for the compilation of water accounts

The procedure we developed is based on (i) the use of existing national statistics or databases that offer detailed coverage of the economic activities of specific industries, (ii) the compilation, using various sources, of a new dataset on water supply and use rates by the 195 industries, and (iii) the choice of aligning parameters that can be used to combine these two sets of data to produce water accounts with a high reliability. The procedure as it is also allows subsequent calculation or estimation of the coverages of the water supply and use data collected in this study. The main statistics and databases applied are listed in Table 1 together with their aligning parameters.

We describe the statistics and databases applied to the various industries listed in Table 1 in Sections 2.3.1 through 2.3.7. In these sections we also detail how the different statistics, registers and databases were used and aligned with the dataset on water supply and use collected in this work to produce the actual water accounts. Detailed lists of the combinations of statistics and databases; data sources on water supply and use rates; and the aligning parameters applied to the 195 industries are supplied in Appendix A1.

2.3. Data sources and compilation

For all 195 industries, data on self-abstracted groundwater, surface water and brackish water were collected, making up the supply table from the environment to the economy. Regarding the water-supply accounts, self-abstracted water was used by the same establishment in a vast majority of cases. Water supply was set to equal with water use as conveyance losses were expected to be zero. Rationale for this is that in these cases water is abstracted in the close vicinity of its subsequent use. Data on self-abstracted water were further divided according to the purpose of use to distinguish cooling water from water used for other purposes.

Table 1
Indicative summary of the main statistics and databases used to describe the extent of the economic activity by five aggregated industries, and the parameters used to align the collected dataset on water-use rates by industry.

Type of industry	NACE codes	Aligning parameter and related primary statistics or database	Specification of water-use data collected
Crop production	011–013	Crop-specific cultivated areas (m^2) from agri- and horticultural statistics	Crop-specific water needs ($m^3/a/m^2$)
Animal husbandry	014	Numbers of different domestic animals (pcs) from number of livestock statistics	Animal-specific water needs (m^3/a/animal)
Aquaculture, mining, manufacturing, energy production and waste management	03–35, 38	Value of revenue (€) from statistics on entrepreneurial activity & mass of production (kg, m^3) from statistics on industrial output	Water use per revenue (m^3/a/€) in individual enterprises; Water use per mass of product (m^3/a/kg), ($m^3/a/m^3$)
Services	40–81, 92–96	Number of employees or value of revenue (€) from statistics on entrepreneurial activity	Water use per employee (m^3/a/person); Water use per revenue in individual enterprises (m^3/a/€)
Households	682	Number of inhabitants from population statistics	Water use per inhabitant (m^3/a/inhabitant)
Public sector	82–93	Total floor areas by the type of building (m^2) from Buildings and Dwellings Register	Water use per floor area by specific types of buildings ($m^3/a/m^2$)

Next, water flows within the economy were compiled, resulting in the mains-water supply and use tables. These tables contained data on the mains-water volumes distributed by the water supply (NACE 36) and subsequently used by the industries to which the water was delivered. The top-down approach used in the compilation of the mains-water supply account is described in Section 2.3.4. The mains-water-use account compilation used a bottom-up approach based on statistics, databases and dataset collection described in Sections 2.3.1 through 2.3.7.

Water is also supplied by industries besides the public water utilities (NACE 36). Water can be self-abstracted by establishments and further delivered to (an)other establishment(s) operating in the same industrial area. In these cases, however, we assigned such water directly to the end user in the use accounts. The primary reason for this has to do with the procedure our accounting follows: The revenues of individual establishments remain unknown if an enterprise has more than one individual establishment. In other words, entries with missing data on revenue cannot be used in the compilation of the accounts. Additionally, the cases in which such inter-industrial water supply and use takes place are generally industrial areas where one operator organizes a water supply for the entire area except for the potable mains water that may be delivered by the municipal water works (NACE 36). The reasons for such organization of water supply are typically historical. It is thus not a generalizable feature of the industry but an outcome of how water supply (including cooling water, process water and tap water) is organized at particular industrial sites. Since this is the case, there is often only one such operator affiliated with a particular industry, which restrains publishing data on these sites, but the total rates are accounted and presented for aggregated industries to make this additional organization of the water supply visible. These accounts, however, are not calculated by using the revenue-based approach for the reasons explained above.

2.3.1. Agriculture - crop production and horticulture

Data on irrigated area, water volumes and sources used for irrigation were obtained from the agricultural census for 2010 [37]. The crop-specific total cultivation areas of vegetables (NACE 01132) and horticultural specialties (NACE 01191) grown in greenhouse were obtained from *Horticultural Statistics* maintained by Natural Resources Institute Finland [38]. Data on water-use volumes together with related cultivation areas were obtained from Kangas et al. [39] and confidentially by request from individual enterprises and consultants.

2.3.2. Agriculture - animal husbandry, fur animal farming and reindeer farming

To estimate the water use in animal husbandry (NACE 0141, 0142, 0143, 0145, 0146, 01471, 01472 and 01479), the total numbers of various domestic animals in 2010 were obtained from the *Number of Livestock Statistics* by Natural Resources Institute Finland [40], which specifies 52 domestic animals by species, gender and age. Water-demand volumes by animal species and age were obtained from Sorvala et al. [41]. For fur animals and reindeers, official statistics are missing. In 2010, there were 1043 fur farms (NACE 01491) operating in Finland, and during the auction period 2009/2010 2,100,000 blue fox skins and 2,000,000 mink skins were produced [42]. Data for drinking water demands of minks and foxes was obtained from Rekilä et al. [43]. Reindeer husbandry (NACE 01492) uses almost exclusively natural pastures. Subsequently, reindeer herds take advantage of snow and natural waters [44].

2.3.3. Mining, manufacturing, energy production and waste management

For the mining and quarrying (NACE 07–09), manufacturing (NACE 10–33), energy (NACE 35) and waste-management (NACE 38) industries, 2010 industry revenue totals were obtained from the *Regional Statistics on Entrepreneurial Activity*, collected by Statistics Finland [34]. For this study, national-level data by industry on total revenues and the numbers of employees in Finland in 2010 were used. The dataset collected covered part of the enterprises operating on these industries. To obtain the revenues of the enterprises included in the collected dataset, we used the open-access internet database provided by Suomen Asiakastieto Oy [45]. The coverage (as percent) of the collected dataset was calculated by summing up the revenues of the enterprises included in the dataset and dividing that sum by the total revenue of the particular industry. For the remaining part of the activities of each industry, a similar pattern of water-use (water source and type along with purpose of water use) than that in the collected dataset was primarily assumed.

Data sources used in the compilation of water supply and use tables are indicated in Appendix A1. For larger industrial establishments operating with an environmental permit granted by a state authority, water abstraction and use data were primarily obtained from a *VAHTI* compliance monitoring *system* where individual establishments report their water-use volumes on an annual basis according to the requirements set in their environmental permits. The *VAHTI* system thus comprises data only for larger establishments that typically use significant volumes of water in their activities. In *VAHTI*, the source of water is specified by using seven categories (ground water, river water, water from a lake or pond, water from a reservoir, brackish water, mains water and water from another establishment), of which the first five represent self-abstraction. In the case of water supplied by another industry (excluding the water-supply industry), the original source of water was tracked down and then categorized accordingly as self-abstraction for the enterprise using the water. For some industries indicated in Appendix A1, statistics on 2010 *Industrial Output* [46] were used together with product-specific water-use rate characterization factors obtained from environmental permits. This approach was applied to lines of manufacture (e.g. production of ready-made concrete) that have a high number of individual establishments and homogenous products. Statistics Finland's *Regional Statistics on Entrepreneurial Activity* microdata were also used to analyze the quality and potential sources of error in the collected dataset.

2.3.4. Water supply and sewerage

Data on the total volume of the mains water supplied by the water utilities (NACE 36) were obtained from the *VELVET* database operated by Finnish Environment Institute. This database comprises data on roughly 1340 water-supply units (municipal water supplies and water-supply cooperatives) and covers a vast majority (> 95%) of operators whose daily volume of supplied water is more than 10 m^3 or that have more than 10 households or 50 persons as customers. Additionally, similar data collected by the National Institute for Health and Welfare, data from Ålands vatten and permits for water abstraction granted by the Environmental and Health Authority on Åland Islands [47] were used to supplement the dataset to cover some water-supply units missing from the *VELVET* database. These data together cover 90.4% of the Finnish population, which equals the estimated total number of citizens living in dwellings connected to water mains. Partially excluded in this dataset are the smallest water cooperatives. Altogether, the dataset is expected to cover > 99% of the mains-water volume provided by the water-supply industry. The shares of raw water source types (surface water, ground water and artificial recharge) for the making of mains water in 2010 were obtained from Laitinen and Lapinlampi [48]. In our study, artificial recharge is regarded as groundwater. Hence, surface water used as raw water for the making of artificial recharge is not considered. For sewerage (NACE 37), water-use data were collected from public reports. An estimate on the average losses in mains-water distribution and on mains-water use by the water supply (NACE 36) was obtained from the Finnish Water Utilities Association (FIWA) [49] and supplemented with data requests.

2.3.5. Services

Data on water used in construction (NACE 41–43), trade (NACE 45–47), transportation (NACE 50–52) and other private and third-sector services (NACE 53–82; 92–96) were collected from public reports of individual enterprises and academic theses. Additionally, confidential data were provided upon request by several enterprises and organizations operating on these industries. For swimming halls and spas (NACE 93), a specific database [50] was used. Volumes of water used for making artificial snow at skiing centers (NACE 93291) were calculated on the basis of water-uptake permits granted by the state authority to a number of operators and their revenues. Similarly, the volume of abstracted water used at golf courses was estimated on the basis of environmental permits, public reports and the total number of golf courses. For religious organizations, data on water use were obtained from individual congregations and public reports. These data included specified water use at cemeteries.

In many service industries, water is used for sanitation purposes only. For these industries, the number of employees was used to estimate the annual volume of mains-water use: The number of employees was multiplied by an average rate of water use (6 m^3/a/employee) estimated for office facilities without staff restaurants by Mutanen [51]. Confidential data provided by individual organizations and enterprises were also used in this context. For maintenance (NACE 331) and construction (NACE 41 and 42) industries, a lower annual rate (1.5 m^3/a/employee) was used based on confidential data provided by individual enterprises. In such cases, the majority of water consumption is allocated to other operators on whose premises the maintenance and construction actually take place.

2.3.6. The public sector

Water use in the public sector, covering educational (NACE 85), health (NACE 86), social (NACE 87–88), cultural (NACE 90–91) and sport services (NACE 93), was calculated by combining two sets of data. First, the total floor volumes of various public buildings were obtained from the *Building and Dwelling Register* (BDR) in the Population Information System of the Finnish Population Register Centre. In this register, all buildings are classified according to their type (intended use). Additionally, information on their use status is given. The types for which the total floor volumes were calculated and the services onto which they were set to affiliate were elementary, high and vocational schools (NACE 85); hospitals and municipal health centers (NACE 86); elderly homes, day care centers and prisons (NACE 87–88); theatres and other buildings for cultural activities, libraries and archives, cinemas and art galleries and halls (NACE 90–91); and indoor ice rinks, sport halls, and tennis, etc., halls (NACE 93). These data were further filtered to exclude buildings that, according to their use-status classification, currently are not being used for the intended purpose (i.e. they are abandoned or destroyed buildings or buildings used for living). By contrast, buildings registered with use status ‘unknown’ were included in the sum, as they typically appeared new or relatively new buildings for which information for the current use has not yet been added to the database. Previously, Vainio et al. [52] concluded that buildings falling into this category in the register are typically in active use for the intended purpose. Based on the random checkups made here, this seemed a valid assumption.

Second, to calculate the water consumption for each of these types of buildings, figures for specific rates of water consumption reported by Ruokojoki [53] were used. The rates were based on questionnaires for cities and municipalities and cover building stock of 45 municipalities of different sizes. This set of data represented municipalities that cover 64.7% of the total population in Finland in 2010. To complete the data collection for the public sector, supplementary data for military (NACE 842), fire departments (NACE 8425), governmental institutions (NACE 72 and 841) and universities (NACE 85) were gathered. For a few governmental organizations for which no measured data on mains-water use was available, an estimate based on the number of employees was used.

2.3.7. Households

Approximately 90% of Finns live in houses connected to water mains. The rest of the population depends on self-abstraction of ground water. Surface water is abstracted for drinking-water purposes very rarely in private households, and its volume is thus negligible. For the estimation of water use by households (NACE 682), an average daily volume of 0.127 m^3 per person was used [49]. In ENVIMAT and other EE-IO models, water-use data must be affiliated with an industry included in the systematics of the ESA [32]. This is the rationale for the water supply and use data related to households being affiliated to letting and operation of real estates (NACE 682) in this paper. To clarify, this industry thus only contains water supply and use data affiliated with households indifferent to the residents' ownership status. In SEEA-Water framework [3], households are presented as a category of its own lacking any ISIC code. Either way, the supply and use rates presented here remain the same as they cover all water supply and use by households and nothing else. The data include all purposes of water use in households.

3. Results

In this chapter, we present various supply and use tables containing data for 195 industries. Next to that, subtotals for 22 aggregated industries are given to ease comparisons between different sectors such as crop production, animal husbandry, food industry, services etc. Each aggregate is formed by industries closely affiliated with each other. Distinctive industries and households (NACE 682) are not included in the aggregates and are indicated in grey in the supply and use tables.

3.1. Water flows: from the environment to the economy

In total, the 195 industries of the Finnish economy abstracted roughly 1960 million m^3 of fresh water from the environment in Finland in 2010 for purposes other than cooling (Table 2). Ground water contributed about 316 million m^3 to this total volume (Appendix B1), and surface water about 1643 million m^3 (Appendix B2). Additionally, ca. 3.7 million m^3 of ground water, and ca. 1891 million m^3 of surface water, were abstracted for cooling (Appendix B3), while brackish water was abstracted for various purposes in a total volume of ca. 6280 million m^3/a (Appendix B4).

3.2. Water flows: within the economy

Within the economy, municipal water suppliers and water cooperatives (NACE 36) distributed 405,289,000 m^3 of water to water mains in 2010. We allocated the total volume of mains water distributed by the water supply industry to the 195 industries of the Finnish economy. To this end, the mains-water-use accounts were populated by using a bottom-up approach. Based on the water-use rates calculated for each industry, a total mains-water consumption of 404,620,000 m^3 was achieved. This corresponds to 99.8% of the mains-water volume distributed. To balance the mains-water supply and use accounts, a requirement of the SEEA-Water framework [3], water-use rates of the 195 industries were calculated accordingly. The mains-water-use table for the Finnish economy in 2010 is presented in Appendix C1. Of the total volume of approximately 405 million m^3 of water distributed, roughly 60 million m^3 was lost in the water mains due to leakages. This volume is allocated to the water supply (NACE 36) in the mains-water-use table (Appendix B5) together with the self-use of mains water by that industry.

Other inter-industrial water flows totaled roughly 139 million m^3; this volume contains all uses of water (Appendix C2) and represents 3.6% of the total volume of water abstracted across all 195 industries in 2010. Of the 195 industries in the dataset, 22 were water-supplying industries, while in total 15 industries used that water. Note that the data in the use table in Appendix C2 are included in the corresponding sectoral figures in Table 2 and Appendix B.

3.3. Data coverage

The quality – that is, the reliability and accuracy – of water accounts depends on the coverage of the data used for their compilation. For this reason, particular focus in our procedure and this paper is on the issues related to data coverage and its transparent reporting.

Data coverages in Table 3 were calculated by comparing the sum of the revenues in the dataset collected in this study to the total revenue of each industry obtained from the *Regional Statistics on Entrepreneurial Activity* [34]. Part of the data used to compile the accounts was provided for confidential use or was otherwise of confidential nature. Therefore, accurate percentages on the data coverages are indicated only for aggregated industries (n = 14), and for individual industries, ranges are used instead (Table 3). To estimate the accuracy of the water accounts, it is not only the dataset coverage but also the intensity of water use of the individual industries that matter. Hence, together with the ranges of data coverage for each industry, a classification according to the water intensity is indicated in Table 3. This classification is based on the total volume of fresh-water use (ca. 3.8 billion m^3): The water intensity of an industry whose contribution to this volume is greater than 1% (> 38 mill. m^3/a) is classified as very high. Subsequent categories are high (> 0.1%–1%), moderate (> 0.01%–0.1%), low (> 0.001%–0.01%) and negligible (< 0.001%, or < 38000 m^3/a). Following this classification, 10, 24, 61, 67 and 33 industries of the total of 195 fell into these respective categories (Table 3). Data in Table 3 also demonstrate the importance of sectoral disaggregation. For instance, manufacturing of household paper products (NACE 1722) belongs to the category with high water-use intensity, while the other subindustries under the NACE 172 heading have low or negligible water intensities.

4. Discussion and conclusions

Lack of non-aggregated, high-quality data has been repeatedly pointed out as a key limitation for water not being an elemental part of various sustainability studies and impact-assessment methodologies dealing with human-environment interactions [5,23,29,30]. Moreover, sectoral aggregation is frequently reported as a major source of error in EE-IO applications exploiting such data [e.g. Refs. [24,25,54]]. In response to these challenges, this paper provides water use and supply tables for abstracted water that cover 195 industries of the Finnish economy. The level of disaggregation in the current paper is thus far greater than in most of the accounts compiled for other countries [5–7,10,11]. The accounts presented in this paper meet the requirements of various EE-IO models that value sectoral disaggregation and distinction between the different types of water sources and uses. We thus consider this work an important step forward in the field of water accounting and the disciplines applying these accounts, such as EE-IO modeling. Compilation of highly disaggregated accounts that distinguish various sources, types and uses of water improve the applicability of

Table 2
The total volume of fresh water self-abstracted from the environment (ground and surface-water bodies) by 195 industries in Finland in 2010. NACE codes are indicated together with abbreviated NACE descriptions. Subtotals for 22 aggregated industries are given. Industries excluded in the subtotals are indicated with asterisk.

Code	Description	(1000 m^3/a)
0111	Cereals, legumes, oil seeds	0
01131	Vegetables in the open	1,732
01132	Vegetables in greenhouse	2,185
01133	Potatoes	782
01134	Sugar beet	0
01191	Horticultural specialties	1,120
0124	Pome and stone fruits	164
0125	Other fruits	506
013	Plant propagation	2,600
	Growing of crops	**9,089**
0141	Dairy cattle	16,474
0142	Other cattle	2,306
0143	Horses	257
0145	Sheet and goat	286
0146	Pigs	2,196
01471	Production of eggs	80
01472	Chickens	133
01491	Fur farming	385
01492	Reindeer farming	0
016	Agriculture spp. a.	0
	Animal husbandry	**22,117**
017	Hunting	0
021	Silviculture	0
022	Logging	0
023	Wild non-wood products	0
024	Forestry spp. a.	0
	Forestry & wild-growing prod.	**0**
0322*	Freshwater aquaculture*	**919,036***
07, 09	Mining and its spp. s.	12,156
08111	Building stone	9
08112	Limestone, gypsum, chalk	517
0812	Gravel, sand, clay, kaolin	8
0891	Fertilizer minerals	466
0892	Peat	130
0899	Mining & quarrying nec.	2,246
	Mining & quarrying	**15,532**
101	Meat prod.	1,517
102	Fish & seafood prod.	6
103	Fruit & vegetable prod.	105
104	Oil & fat prod.	18
1051	Milk prod. & cheese	4,875
1052	Ice cream	28
1061	Grain mill prod.	0
1062	Starch prod.	86
107	Bakery prod.	38
1081	Sugar	1,109
1082	Confectionery	139
1083	Tea & coffee	0
1084	Condiments	0
1085	Prepared meals	0
1086	Homogenized food prod.	0
1089	Food prod. nec.	244
109	Animal feeds	14
	Food industry	**8,179**
1101	Spirits	1,891
1105	Beer	858
1106	Malt	695
1107	Soft drinks, water	136
	Beverage industry	**3,580**
13	Textiles	699
14	Wearing apparel	136
15	Leather	212
	Textiles, wearing apparel & leather	**1,047**
161	Sawmilling	660
162	Wood prod.	3,633

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Table 2 (*continued*)

Code	Description	(1000 m^3/a)
171	Pulp & paper	1,083,058
17211	Paper sacks and bags	0
17212	Corrugated paper prod.	0
1722	Household paper prod.	8,825
1729	Paper prod. nec.	0
	Forest industry	**1,096,176**
18*	Printing*	1,224*
192	Refined petroleum prod.	7,483
2011	Industrial gases	32,266
2012	Dyes & pigments	65,339
2013	Inorganic basic chemicals	79,427
2014	Organic basic chemicals	80,887
2015	Fertilizers	61,152
2016	Primary plastics	34,594
2017	Synthetic rubber	14,460
203	Paints, inks & coatings	40
204	Detergents & perfumes	34
205	Chemical prod. nec.	8,320
210	Pharmaceuticals	31
221	Rubber prod.	7,899
222	Plastics prod.	1,978
	Refined petroleum prod. & chemicals	**393,910**
2312	Flat glass processing	129
2313	Hollow glass	220
2314	Glass fibres	4,211
232-3	Clay building materials	6
234	Other ceramic prod.	90
2351	Cement	639
2352	Lime & plaster	2,178
2361	Concrete prod.	91
2362	Plaster prod.	78
2363	Ready-mixed concrete	0
2364	Mortars	0
2365	Fibre cement	15
237	Stone processing	29
2391	Abrasive prod.	8
2399	Non-metallic prod. nec.	182
	Mineral products	**7,876**
241	Basic iron & steel	82,257
242	Steel pipes	1,950
244	Basic non-ferrous metals	35,901
245	Casting of metals	1,879
	Basic metal industry	**121,987**
251	Structural metal prod.	131
252	Metal tanks & containers	0
253	Steam generators	66
254	Weapons & ammunition	0
256	Treatment & coating of metals	125
257	Cutlery, tools & general hardware	31
259	Other fabricated metal prod.	233
	Metal products	**586**
261	Electrical components	20
263	Communication eq.	0
265	Measuring & testing appl.	0
266	Irradiation & electromedical eq.	0
271	Electrical motors & generators	92
273	Wiring & wiring devices	592
274	Electrical lighting eq.	0
275	Domestic appl.	1
279	Electrical eq. nec.	600
	Electrical products	**1,305**
281	General-purpose machinery	0
282	General-purpose machinery nec.	0
283	Agric. & forestry machinery	32
284	Metal forming machinery	0
289	Special-purpose machinery nec.	5,080
291	Motor vehicles	520
292	Motor vehicle bodies & trailers	0
293	Motor vehicle parts & accessories	5

(*continued on next page*)

Table 2 (*continued*)

Code	Description	(1000 m^3/a)
301	Ships & boats	50
302–9	Other transportation eq.	8
	Machinery	**5,695**
310	Furniture	0
321	Jewellery & bijouterie	0
323	Sports goods	0
325	Medical & dental instruments	0
331	Metal prod. & machinery repair	148
332	Machinery & eq. installation	0
	Other manufacturing	**148**
351	Electricity	800,029
35301	District heat & cool	146
35302	Heat & cool for industry	31,855
36	Water supply	405,289
37	Sewerage	0
381	Waste collection	7
382	Waste treatment	267
383	Material recovery	36
	Energy, water & waste	**1,237,629**
41	Construction	0
42	Civil engineering	3
43	Specialized construction a.	0
45	Trade & repair of motor vehicles	0
461e	Wholesale nec.	0
463	Wholesale of food	0
471–2	Retail trade of food	0
473	Fuel retail trade	0
474–7	Retail trade nec.	0
49	Land transportation	0
50	Water transportation	0
51	Air transportation	0
52	Transportation spp. a.	21
53	Postal & courier s.	0
	Construction, trade & transportation	**24**
55	Accommodation	32
56	Restaurants	0
58	Publishing	0
59–60	Broadcasting	0
61	Telecommunications	0
62	Computer programming	0
63	Information	0
64	Finance	0
65	Insurance	0
66	A. aux. to finance & insurance	0
682*	Real estates*	24,917*
683	Real estate a.	0
69	Legal & accounting s.	0
70	Head offices	0
71	Engineering a. & technical testing	0
72	Scientific R&D	42
73	Advertising & marketing	0
74	Scientific & technical. s. nec.	0
75	Veterinary s.	0
77	Rental & leasing	0
78	Employment s.	0
79	Travel agencies	0
80	Security s.	0
81	S. to buildings & landscape a.	100
82	Office s.	0
	Services in industries 55-82	**174**
841	Public administration	12
842	Defence	769
8425	Fire departments	71
843	Social security	0
846	Road maintenance	0
85	Education	355
86	Health	186
87–88	Social work	37

(*continued on next page*)

Table 2 (*continued*)

Code	Description	(1000 m^3/a)
	Administration, education & health	**1,430**
90	Culture	0
92	Gambling & betting	0
931	Sports a.	4,351
932e	Amusement parks & recreation a.	17
93291	Skiing centres	4,430
	Culture & sports	**8,798**
94e	Membership organizations	0
9491	Religious organizations	702
95	Repair of personal goods	0
9601	Washing & dry-cleaning	0
9602	Beauty treatment	0
9603–4	Personal s. nec.	0
	Personal services	**702**
	All Industries	**3,881,161**

a. = activities; appl. = appliances; aux. = auxiliary; eq. = equipment; nec. = not elsewhere classified; prod. = products; spp. = supporting; s. = services.

the water accounts. Consequently, this work responds to the concerns presented by Vardon et al. [13] that the needs of accounting data users and the actions taken by the producers of these data should meet better than they do today.

4.1. Data quality, coverage and sources of error

In the context of water accounting, quality and coverage of data have not been studied. To our knowledge, this is the first paper to report these issues in the context of national water accounts and to present a procedure that helps to address them in a systematic, transparent and scientifically sound way. Our paper thus makes a significant contribution to the development of the hitherto missing data-quality frameworks called for by the SEEA-Water guidelines [3]. In this section, we discuss the potential sources of error in the water accounts reported for the 195 industries of the Finnish economy and analyze their relevance to suggest corrective measures.

Two types of errors can be identified. First, poor coverage or misrepresentation may result in unreliable estimates of the total water supply and/or use. Second, in the case of high coverage, these rates are likely correct but incorrectly allocated to different accounts (self-abstracted vs. mains water). We start by analyzing the sectors with poor data coverage. By comparing water-use intensities and coverages by industry in Table 3, the data gaps and uncertainties with the potentially highest impact on the accuracy of the water accounts can be identified. For nine out of ten of the industries with very high water intensity, the collected dataset represents over 75% – and in many cases over 90% – of the economic activity of the industry as measured by revenue or output volume (Table 3). Households (NACE 682) are also characterized by a very high intensity of water use. By contrast, 7 out of 14 of the industries with very limited (< 10%) dataset coverage belong either to the category of low or negligible water-use intensity. Six of these 14 industries are classified by a medium water-use intensity: metal product and machinery repair (NACE 331), trade and repair of motor vehicles (NACE 45), wholesale trade excluding food and beverages (NACEs 461–2– and 464–469), transportation supporting activities (NACE 52), religious organizations (NACE 9491) and beauty treatment (NACE 9602). The remaining industry, restaurants (NACE 56), has a high water-use intensity. Further attempts to improve the accuracy of water accounts should focus primarily on these seven industries. This could be achieved by organizing additional surveys on water-use rates and revenues targeting enterprises or establishments in these industries.

Next we discuss the potential for incorrect allocation of water supply and use. For mains-water supply and use accounts, we used top-down and bottom-up approaches, respectively. Both resulted in high correspondence. The mains-water use account covered 99.8% of the mains-water supply. This is in line with the high sectoral data coverages achieved. Nevertheless, errors in mains-water-use rates by industry may also balance out each other. Therefore, we discuss the key sources of error in our water supply and use accounts. Next, we go through all the main approaches listed in Table 1 – data based on crop-specific areas of cultivated land, numbers of animals, revenues, numbers of employees – to address the potential sources of error related to each of them.

In a global perspective, irrigation for crop production dominates water-use statistics [55]. In Finland, irrigation is negligible; only 3% of the country's cultivated area has facilities for it, and they are used at a variable rate depending on weather conditions during each growth season. Even then, irrigation is limited to a handful of crops, the most notable ones being berries and fruits, potatoes, some vegetables and horticultural specialties (see Table 2 and Appendix C1). Irrigation volumes are generally not measured, with the exception of the autonomous region of Åland Islands, where water abstraction permits often set requirements for metering and reporting of abstracted water volumes. Subsequently, water supply and use data for crop production are based on modeled data [37]. However, since the data on cultivated area for each crop are accurate, and the water needs for the relevant species are well known, these water-use estimates can be regarded reliable. According to the Information Centre of the Ministry of Agriculture and Forestry [37], only 1.9% of irrigation water is mains water, while the shares of surface water and ground water are 91.8% and 4.8%, respectively. Irrigation thus has negligible impact on mains-water use.

Table 3

Coverages of the dataset by industry used in the compilation of water accounts for 195 industries in Finland in 2010 and their water intensities (I). Intensity is very high (VH), high (H), medium (M), low (L), or negligible (N) for annual total water use > 38 mill. m^3, > 3.8 mill. m^3 to 38 mill. m^3, > 380,000 m^3 to 4.2 mill. m^3, > 38,000 m^3 to 380,000 m^3 and < 38,000 m^3, respectively. NACE codes are indicated together with abbreviated NACE descriptions. Accurate coverages (%) for 14 aggregated industries are given. Non-aggregated industries are indicated with light grey. a. = activities; appl. = appliances; aux. = auxiliary; eq. = equipment; nec = not elsewhere classified; prod. = products; spp. = supporting; s. = services, n.a. = not assessed. Non-aggregated industries are indicated with an asterisk.

Code	Description	(%)	I
0111	Cereals, legumes, oil seeds	n.a.	N
01131	Vegetables in the open	n.a.	M
01132	Vegetables in greenhouse	> 25-50	H
01133	Potatoes	n.a.	M
01134	Sugar beet	n.a.	N
01191	Horticultural specialties	> 10-25	M
0124	Pome and stone fruits	n.a.	L
0125	Other fruits	n.a.	M
013	Plant propagation	n.a.	M
	Growing of crops	**n.a.**	
0141	Dairy cattle	n.a.	H
0142	Other cattle	n.a.	M
0143	Horses	n.a.	M
0145	Sheet and goat	n.a.	M
0146	Pigs	n.a.	M
01471	Prod. of eggs	n.a.	L
01472	Chickens	n.a.	M
01491	Fur farming	n.a.	M
01492	Reindeer farming	n.a.	N
016	Agriculture spp. a.	n.a.	N
	Animal husbandry	**n.a.**	
017	Hunting	n.a.	N
021	Silviculture	n.a.	N
022	Logging	n.a.	N
023	Wild non-wood products	n.a.	N
024	Forestry spp. a.	n.a.	N
	Forestry & wild-growing prod.	**n.a.**	
0322*	Freshwater aquaculture*	> 75	VH
07, 09	Mining and its spp. s.	> 75	H
08111	Building stone	> 50-75	N
08112	Limestone, gypsum, chalk	> 75	M
0812	Gravel, sand, clay, kaolin	n.a.	N
0891	Fertilizer minerals	> 75	M
0892	Peat	> 75	L
0899	Mining & quarrying nec.	> 75	M
	Mining & quarrying	**90**	
101	Meat prod.	> 75	H
102	Fish & seafood prod.	> 50-75	L
103	Fruit & vegetable prod.	> 50-75	M
104	Oil & fat prod.	> 75	L
1051	Milk prod. & cheese	> 75	H
1052	Ice cream	> 75	L
1061	Grain mill prod.	> 75	N
1062	Starch prod.	> 75	L
107	Bakery prod.	> 10-25	M
1081	Sugar	> 75	M
1082	Confectionery	> 75	M
1083	Tea & coffee	> 75	N
1084	Condiments	> 75	L
1085	Prepared meals	> 75	M
1086	Homogenized food prod.	> 75	L
1089	Food prod. nec.	> 50-75	M
109	Animal feeds	> 75	L
	Food industry	**81**	
1101	Spirits	> 75	M
1105	Beer	> 75	M
1106	Malt	> 75	M
1107	Soft drinks, water	> 25-50	L
	Beverage industry	**81**	
13	Textiles	> 50-75	M
14	Wearing apparel	> 75	L
15	Leather	> 50-75	M

(*continued on next page*)

Table 3 (*continued*)

Code	Description	(%)	I
	Textiles, wearing apparel & leather	**71**	
161	Sawmilling	> 25-50	M
162	Wood prod.	> 50-75	H
171	Pulp & paper	> 75	VH
17211	Paper sacks and bags	> 10-25	N
17212	Corrugated paper prod.	> 25-50	L
1722	Household paper prod.	> 75	H
1729	Paper prod. nec.	> 25-50	N
	Forest industry	**57**	
18*	Printing*	> 25–50	M
192	Refined petroleum prod.	> 75	H
2011	Industrial gases	> 75	M
2012	Dyes & pigments	> 75	VH
2013	Inorganic basic chemicals	> 75	VH
2014	Organic basic chemicals	> 75	VH
2015	Fertilizers	> 75	VH
2016	Primary plastics	> 75	H
2017	Synthetic rubber	> 75	H
203	Paints, inks & coatings	> 75	L
204	Detergents & perfumes	> 75	L
205	Chemical prod. nec.	> 75	H
210	Pharmaceuticals	> 75	M
221	Rubber prod.	> 75	H
222	Plastics prod.	> 25-50	M
	Refined petroleum prod. & chemicals	**91**	
2312	Flat glass processing	> 50-75	M
2313	Hollow glass	> 50-75	L
2314	Glass fibres	> 25-50	H
233	Clay building materials	> 75	L
234	Other ceramic prod.	> 75	L
2351	Cement	> 75	M
2352	Lime & plaster	> 75	M
2361	Concrete prod.	n.a.	M
2362	Plaster prod.	> 75	L
2363	Ready-mixed concrete	n.a.	M
2364	Mortars	> 25-50	N
2365	Fibre cement	> 75	N
237	Stone processing	> 25-50	L
2391	Abrasive prod.	> 75	L
2399	Non-metallic prod. nec.	> 75	L
	Mineral products	**78**	
241	Basic iron & steel	> 75	VH
242	Steel pipes	> 75	M
244	Basic non-ferrous metals	> 75	H
245	Casting of metals	> 75	M
	Basic metal industry	**89**	
251	Structural metal prod.	> 10-25	M
252	Metal tanks & containers	> 25-50	N
253	Steam generators	> 25-50	L
254	Weapons & ammunition	> 75	L
256	Treatment & coating of metals	> 10-25	M
257	Cutlery, tools & general hardware	> 25-50	L
259	Other fabricated metal prod.	> 25-50	M
	Metal products	**41**	
261	Electrical components	> 25-50	L
263	Communication eq.	> 75	L
265	Measuring & testing appl.	> 25-50	M
266	Irradiation & electromedical eq.	> 25-50	N
271	Electrical motors & generators	> 75	L
273	Wiring & wiring devices	> 50-75	M
274	Electrical lighting eq.	> 1-10	N
275	Domestic appl.	> 25-50	N
279	Electrical eq. nec.	> 10-25	M
	Electrical products	**45**	
281	General-purpose machinery	> 50-75	L
282	General-purpose machinery nec.	> 25-50	L
283	Agric. & forestry machinery	> 50-75	L
284	Metal forming machinery	> 25-50	L
289	Special-purpose machinery nec.	> 25-50	H

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Table 3 (*continued*)

Code	Description	(%)	I
291	Motor vehicles	> 50-75	M
292	Motor vehicle bodies & trailers	> 25-50	L
293	Motor vehicle parts & accessories	> 1-10	N
301	Ships & boats	> 50-75	M
302–9	Other transportation eq.	> 50-75	L
	Machinery	**51**	
310	Furniture	> 10-25	L
321	Jewellery & bijouterie	> 25-50	N
323	Sports goods	> 25-50	N
325	Medical & dental instruments	> 50-75	L
331	Metal prod. & machinery repair	> 1-10	M
332	Machinery & eq. installation	> 25-50	L
	Other manufacturing	**33**	
351	Electricity	> 75	VH
35301	District heat & cool	> 25-50	M
35302	Heat & cool for industry	> 75	H
36	Water supply	> 75	VH
37	Sewerage	> 10-25	M
381	Waste collection	> 75	N
382	Waste treatment	> 10-25	M
383	Material recovery	> 75	L
	Energy, water & waste	**72**	
41	Construction	n.a.	L
42	Civil engineering	> 1-10	L
43	Specialized construction a.	> 1-10	N
45	Trade & repair of motor vehicles	> 1-10	M
461e	Wholesale nec.	> 1-10	M
463	Wholesale of food	> 25-50	M
471–2	Retail trade of food	> 25-50	M
473	Fuel retail trade	> 10-25	M
474–7	Retail trade nec.	> 10-25	L
49	Land transportation	> 10-25	M
50	Water transportation	> 75	M
51	Air transportation	> 50-75	L
52	Transportation spp. a.	> 1-10	M
53	Postal & courier s.	> 75	L
	Construction, trade & transportation	**28**	
55	Accommodation	> 10-25	H
56	Restaurants	> 1-10	H
58	Publishing	n.a.	L
59–60	Broadcasting	> 25-50	L
61	Telecommunications	> 25-50	L
62	Computer programming	n.a.	L
63	Information	n.a.	N
64	Finance	n.a.	L
65	Insurance	n.a.	L
66	A. aux. to finance & insurance	n.a.	N
682*	Real estates*	n.a.	VH
683	Real estate a.	n.a.	L
69	Legal & accounting s.	n.a.	L
70	Head offices	n.a.	L
71	Engineering a. & technical testing	n.a.	L
72	Scientific R&D	n.a.	L
73	Advertising & marketing	n.a.	L
74	Scientific & technical. s. nec.	n.a.	L
75	Veterinary s.	> 1-10	L
77	Rental & leasing	> 1-10	L
78	Employment s.	n.a.	L
79	Travel agencies	n.a.	N
80	Security s.	n.a.	N
81	S. to buildings & landscape a.	> 10-25	M
82	Office s.	n.a.	L
	Services in industries 55–82	**n.a.**	
841	Public administration	> 75	M
842	Defence	> 75	M
8425	Fire departments	< 1	L
843	Social security	n.a.	L
846	Road maintenance	n.a.	L
85	Education	n.a.	H

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Table 3 (*continued*)

Code	Description	(%)	I
86	Health	n.a.	H
87–88	Social work	n.a.	H
	Administration, education & health	**n.a.**	
90	Culture	n.a.	L
92	Gambling & betting	> 75	N
931	Sports a.	n.a.	H
932e	Amusement parks & recreation a.	n.a.	L
93291	Skiing centres	> 50-75	H
	Culture & sports	**n.a.**	
94e	Membership organizations	n.a.	N
9491	Religious organizations	> 1-10	M
95	Repair of personal goods	n.a.	N
9601	Washing & dry-cleaning	> 50-75	M
9602	Beauty treatment	< 1	M
9603–4	Personal s. nec.	n.a.	N
	Personal services	**n.a.**	
	All Industries	**n.a.**	

In animal husbandry, reported farm-level data on water supply and use are scarce. By contrast, the statistics on animal numbers are highly accurate, and as the water needs per animal can be regarded quite constant, the total water use in this industry can be estimated relatively reliably. The supply of water to animal husbandry, however, is a more complicated issue. Some farms use exclusively self-abstracted ground water, others depend on mains water, and many supplement self-abstraction with water bought from local water supply. The source of water used depends on production line as well. According to Sorvala et al. [41], whose estimates on water-use rates per animal and sources for supplied water were used to calculate water supply and use data in our study, chicken farms largely depend on mains water while dairy cattle farms tend to be the most self-sufficient in terms of water supply. The uncertainty in the agricultural mains-water consumption may thus either underestimate or overestimate the mains-water consumption and thus cause imbalance in the mains-water-use table. Since raising of dairy cattle in particular is characterized by a high water-use intensity (Table 3), the above uncertainties require further attention in future research and data collection aimed at the elimination of errors in water supply and use accounts.

Industries for which revenue was used as the basis for our calculations of the water use and supply data cover > 98% of the total abstraction volumes presented in the water-supply table (Table 2). The potential errors in the revenue-based approach thus deserve particular attention. In the revenue-based approach, two separate background datasets, not completely aligned with each other in regard to NACE affiliation, were used. First, to obtain the total revenues of the industries on a national level, *Regional Statistics on Entrepreneurial Activity* [34] were used. These statistics were compiled from data for individual establishments rather than individual enterprises. An enterprise having several establishments across the country may thus have establishments in more than one industry represented in these statistics. By contrast, data on the revenues of the enterprises included in the dataset collected in this study were obtained from the web portal of Suomen Asiakastieto Oy [45], in which revenues are reported for the entire enterprise. In the latter database, the enterprise is affiliated to one industry (NACE class), which is determined by the main source of revenue of that enterprise. Thus, such an enterprise may have several establishments, and these individual establishments may be affiliated to different NACE classes in the *Statistics on Regional Entrepreneurial Activity* [34]. To evaluate the significance of this methodological limitation, we analyzed the microdata in *Statistics on Regional Entrepreneurial Activity* provided by Statistics Finland. From the entire dataset (n = 9970), entries displaying a difference between the NACE affiliation of a local establishment and the entire enterprise were identified. Single establishments appear several times in the dataset, because data are organized according to the various goods produced following the European System of production statistics for mining and manufacturing (PRODCOM) classification. The identified cases were then compared with the corresponding information in our dataset used for water accounting and obtained e.g. from *VAHTI* and from the database of Suomen Asiakastieto Oy [45]. Entries for which the difference in the NACE affiliation appeared on a higher digit-level than that used in our dataset were disregarded. Similarly, entries for which corresponding differences were already identified when compiling the initial dataset from the primary data sources used (*VAHTI*, Suomen Asiakastieto Oy [45] etc.), were ruled out.

The remaining entries represented roughly 3% of the entire dataset, with 9970 entries and spread to 46 of the 195 industries distinguished in this study. These entries were dominated by the following industries: manufacturing of metal products (NACE 25), manufacturing of machinery (NACE 28), repair and installation of machinery and equipment (NACE 33) and manufacturing of basic chemicals etc. (NACE 201) by shares of 30%, 17%, 12% and 8%, respectively. The dominance of the first three industries likely reflects the business model of the machinery-manufacturing industry: individual companies handle their own manufacturing of metal parts used in machines, and the maintenance and repair services of these machines. This may result in an imbalance in the water-use rates by industry – within the metal product and machinery manufacturing industries in particular – but less impact on the overall balance in the water supply and use tables. Another source of error arises from the fact that in our collected dataset, micro and small enterprises are underrepresented. While their water supply and use rates may differ from those of larger enterprises, we expect this to have a minor impact on the accuracy of the accounts reported.

A further potential source of error in this approach is that some of the establishments of an individual enterprise may not be covered when their water supply and/or use data are compiled. This may be the case for enterprises having an environmental permit granted by a governmental authority only for some of their establishments. In such cases, separate establishments without manufacturing facilities (e.g. headquarters and other administration) are often not included in the dataset. Similarly, enterprises tend to report their water-use rates without specifying whether the reported data cover all of their local establishments or whether a water-use estimate is applied for the establishments excluded in their internal reporting system. Even though specific attention was paid to this issue upon the data collection, both of these shortcomings result in underestimated water supply and/or use rates by those industries.

In industries that abstract water for several purposes, potentially including cooling, processing and sanitation, the total abstracted volume needs to be allocated for cooling and other purposes. As the volumes used for cooling are generally very high in comparison with other uses, it is essential to make a distinction between them in the accounting. Here, environmental permits of individual production sites were additionally used, where necessary, to allocate the abstracted volumes to two categories: cooling water and other uses. Exact information on this division was, however, not found for a handful of establishments with high total-water consumption, and minor uncertainty thus remains here.

In the service industries, actual data was often scarce or completely missing. For this reason, water-use rates were estimated on the basis of the numbers of employees. For the overall allocation of mains water, service industries as a whole have less impact, since many of the individual service industries have negligible or low water-use intensities (Table 3). However, six industries within trade and services belonging to the group of the poorest data-coverage categories were also classified as high water-use intensity industries. Improvement of data coverage for these industries should be prioritized.

4.2. Implications on SEEA-Water and water accounting internationally

Methodologically, the water supply and use tables compiled in this paper are close to the standard physical supply and use tables described in the SEEA-Water framework [3]. A handful of exceptions, however, can be found between our approach and the guidance in the SEEA-Water framework. First, our water accounts focus on water that is physically abstracted from the environment by humans. Subsequently, soil water originating from precipitation and used by agricultural crops is not considered here. Lai et al. [56] previously suggested incorporating rain water used by plants into ecosystem service accounts according to the SEEA-EEA manual [57]. However, it is not only agriculture that benefits from and depends on rain water but also industries such as forestry and logging (NACE 02) and nature reserve activities (NACE 9104). We therefore call for better coherence in the SEEA-Water guidance with regard to soil water accounting. We also consider hydroelectric power generation and in-stream aquaculture to be in-stream uses of water, for which ecosystem service accounting is a more appropriate context.

Another difference is that we distinguish water used for cooling purposes from other uses of water. This is essential for the application of the water-use data in EE-IO modeling [22] or LCA-based analysis [58], because in those applications, cooling water is often regarded as its own category. This is understandable for three reasons: First, it doesn't undergo major chemical or volumetric changes during its use; second, the chemical and/or microbiological quality requirements for it are not as high as they are for water that is used as a raw material for the production of various goods or mains water; and third, its large volumes would easily overshadow other uses of water and thus hamper the application and interpretation of the accounts. The SEEA-Water manual recognizes the volumetrically dominating role of cooling-water use and suggests reporting that water use separately in the energy industry. This study demonstrates that cooling water contributes significantly to the total water use in many other industries (Appendices B3 and B4). Hence, making this distinction systematically is of great relevance for the applicability of water supply and use accounts in the compilation of water-emission accounts and other accounts dealing with return flows. If this is not done, water flows returned directly to the environment without any treatment (cooling water), treated waste waters from the processes containing residual process chemicals, and the sanitation water flows with their composition different from the previous two waste-water types cannot be kept apart. In our view, SEEA-Water guidance would benefit from a more systematic way of dealing with cooling water accounting.

A highly relevant question is whether the procedure used to compile the data reported in this paper could be applied in other counties. In our view this should be possible. First, we used standard statistical data on economic activities collected, for instance, in all EU countries. In this study, revenues, employee numbers, production volumes, crop-specific cultivated areas, floor areas and animal numbers were used to align different sets of data. Similar statistics and data are available in most industrialized countries. Additionally, the procedure is not bound to the use of exactly the same types of statistics or databases, so alternative approaches can be chosen where justified.

In our procedure, the dataset-collected water use by individual enterprises is related to their revenue. Thus, if an enterprise's water-use rate (m^3/a) changes, but revenue (€/a) remains the same (or vice versa) the water-use-to-revenue ratio (m^3/€) of the enterprise will change. This will correspondingly impact the water-use rate of the industry. Hence, any enterprise-level changes in production affecting this ratio will thus be revealed by the dataset collected. In general, water supply and use data by industry are unlikely to see dramatic annual changes that would arise from rapid changes in technology affecting water-use efficiency, or the patterns of production or consumption. In conclusion, we estimate that this accounting could be repeated every five years. Even though the procedure developed and the dataset collected here provide a solid basis for the future updating of the accounts, updating the data remains labor intensive and cannot be automated for now. Therefore, for annual reporting, estimates based on simple modeling that builds on water intensities (m^3/€) and values of revenue (€/a) by industry in annually updated standard national accounts could be used. Such modeling would assume a constant water-use-to-revenue ratio for the last four consecutive years, an assumption which merits testing.

4.3. Implications on future research

This paper presented a novel procedure by which water supply and use accounts with a high level of disaggregation – 195 industries – were compiled. It also allows transparent assessment and reporting of data-quality issues such as the coverage of the dataset used and the potential sources of error. In our view, similar data-quality issues should be a priority in any future reporting of water accounting as that is the only way other scholars applying the data can evaluate the reliability and uncertainties related to the data they use.

In this case study, the accounts were compiled on a national level by using Finland as an example. The procedure developed can be applied to other geographic regions nationally and internationally. For instance, regional water accounts for river basin districts related to the implementation of WFD are among potential future applications. This way, water accounts could also be linked with ecosystem service accounting and sustainability assessment on the use of water resources. The procedure can also be applied to the compilation of other environmental accounts such as those related to energy and waste. Naturally, accounts for return flows within the economy and from the economy to the environment, as well as water emission accounts, constitute a highly relevant and potential application of the procedure and the current accounts.

The water supply and use data presented here provide multiple interesting options for future sustainability studies, in particular in the field of EE-IO modeling. In follow-up studies, the water accounts presented here will be merged with the ENVIMAT model to examine the water productivity of the industries, and comparisons between water supply and use rates based on actual (this study) and modeled data will be made. For EE-IO modeling, highly disaggregated data are needed. To this end, we suggest that in the field of water accounting, effort should be put towards the production of accounts with disaggregated data rather than, for instance, annual reporting of water supply and use data for aggregated industries. By producing data that is easily applicable to further analyses, improved societal impact of water accounting could be expected.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at mailto:http://dx.doi.org/10.1016/j.wre.2018.05.001.

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