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German water accounts: New methodology and estimation of annual results

Final technical report on water flow accounts within the project of enhancing environmental-economic accounts reporting on water, wastewater and emissions to water

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Abbreviations and acronyms

AAT	Asset accounts table
AC	Accommodations
AIC	Akaike information criterion
ARIMA	Auto-regressive integrated moving average
BDEW	Bundesverband der Energie- und Wasserwirtschaft [German Association of Energy and Water Industries]
BfG	Bundesamt für Gewässerkunde [Federal Office for Hydrology]
CL	Camping locations
CPA	Classification of Products by Activity
DED	Decentralised disposal
DID	Direct discharge
DIMESA	Directors of Sectoral and Environmental Statistics and Accounts
DIS	Discharge of water into the environment
DP	Deep percolation
E 36	Public water supply
E 37	Public wastewater disposal
EG	Enriched groundwater
ES	Economic sector
EUROSTAT	European Statistical Office
EW-MFA	Environmental accounts on economy-wide material flow accounts
FW	Freshwater, excluding discharged unused water
IP	Water incorporated into plants
ISIC	International Standard Industrial Classification
IW	Irrigation water
IWS	Improving waste statistics
MFA	Material flow accounts
NACE	Statistical Classification of Economic Activities in the European Community
NSC	Non-surveyed companies
OA	Own abstraction
OS	Overnight stays
PHH	Private households
PSUT	Physical supply and use tables
PWFA	Physical water flow accounts
PWS	Public water supply
PWW	Public wastewater

RT	Reported travels
SAS	Statistical analysis software
SC	Small companies
SEEA-CF	System of Environmental Economic Accounting-Central Framework
SSM	State-space model
ST	Number of students
StBA	Statistisches Bundesamt [Federal Statistical Office Germany]
TA	Travels abroad
TD	Domestic travels
TP	Transpiration
TWV	Traded water volumes
UCM	Unobserved components model
UStatG	Umweltstatistikgesetz [German National Environmental Statistics Act]
WA	Water accounts
WCL	Water content level
WCONS	Water consumption - including evaporation, transpiration and incorporation into products
WCONT	Water content
WE	Weight of traded products
WL	Water loss
WSP	Wasserstatistik zur öffentlichen Wasserversorgung und öffentlichen Abwasserentsorgung [Water statistics on public water supply and sewage disposal]
WSNP	Wasserstatistik zur nicht-öffentlichen Wasserversorgung und nicht-öffentlichen Abwasserentsorgung [Water statistics on non-public water supply and sewage disposal]
WUSE	Water use
WW	Wastewater

Coefficients

[A]	level of freshwater used by an economic sector
[B]	share of non-surveyed companies within an economic sector
[C]	water loss coefficient
[D]	share of irrigation water in total water use by an economic sector
[E]	average share of water incorporated into plants
[F]	share of small industries in water use by private households
[G]	share of residents not connected to the public water suppliers
[H]	share of decentralised disposal
[J]	share of residents operating septic wastewater tanks
[K]	share of irrigation in water use by private households
[L]	value for daily water use per capita excluding small companies
[M]	value for daily water use per capita including small industries
[N]	share of German travels abroad in total amount of travels

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1 Project objectives and activities

This final report is part of the Eurostat project 2020-DE_IWSWAMFA, consisting of the three subprojects:

- Improving waste statistics (IWS)
- Improving water accounts (WA)
- Improving material flow accounts (MFA)

The following report covers the subproject 'improving water accounts' (WA). This subproject aims to redesign the German water accounts in order to align them more closely to international and European methodological standards. As a key part of environmental-economic accounts, providing a comprehensive quantitative overview of interactions between the environment and the economy, the water accounts in particular describe water and wastewater flows between the natural and the economic worlds, including private households. This project report presents the main results of the project work conducted between July 2021 and September 2023.

German water accounts have a long tradition and data are available starting with the reporting year 1995. They provide comprehensive information about water withdrawal from different natural water resources, water use by the German economy and residents and, last but not least, the return of wastewater to the environment. Water accounts are compiled in a way that combines information from different official statistics, as well as additional data sources and estimation approaches, to build an integrated accounting framework. The official German water statistics constitute the main data source of the German water accounts. They consist of several surveys conducted by the German official statistics network, i.e. the Federal Statistical Office and the *Land* Statistical Offices. Their results are presented in several separate publications, most notably water statistics on public water supply and sewage disposal (WSP) and water statistics on non-public water supply and sewage disposal (WSNP). The water statistics' high level of detail in the data collection, comprising more than 120 questionnaire positions, enables the water accounts to give detailed information covering more than 60 NACE (Statistical Classification of Economic Activities in the European Community) categories, for example, and to differentiate eight sources of abstracted water, giving space to a wide range of fields of application.

Up until now, the German water accounts have been published on a triennial basis. The reason for this was that the main data source – the German water statistics – collect their data only every three years, to keep the administrative burden on surveyed companies at a reasonable level.

Since the first publication of the German water accounts, various international and European frameworks on environmental-economic accounts in general and on water accounts in particular have been established or further developed. Especially worth mentioning in the context of this project are the United Nations publications 'System of Environmental-Economic Accounting – Central Framework' (SEEA-CF) and 'SEEA-Water', both dating from 2012, as well as the Manual of Physical Water Flow Accounts published by Eurostat in 2014. More recently, in 2021, Eurostat presented and discussed with European member states a proposal for harmonised European water accounts, amongst others at a meeting of the Directors of Sectoral and Environmental Statistics and Accounts (DIMESA) from 30 June to 1 July 2021. Even though the proposed module on water accounts has ultimately not been adopted and thus not been added to regulation (EU) 691/2011 on environmental accounts, it still provides some additional guidance on this matter, as it represents the most recent state of debate regarding water accounts in Europe.

Against this backdrop, the project work aimed to redesign German water accounts in order to more closely align them to the existing international and European conceptual frameworks, also in light of developments in potential data sources and estimation methods. As a conceptual basis for the redesigning, this mainly concerns the physical supply and use tables (PSUT) from the internationally agreed SEEA-CF as well as the simplified asset accounts table (AAT) from Eurostat's aforementioned proposal on European water accounts from 2021. While the PSUT describe different water flows between the environment and economic entities, the AAT balances additions to and abstraction from a country's water stocks. Several other frameworks, for example the SEEA-Water and Eurostat's Manual of Physical Water Flow Accounts were also consulted for additional insights. Notably, the scope of data in the new German water accounts has now significantly expanded compared to the previous accounts.

The first step of the project comprised an in-depth review of contents and structures of the previous implementation of German water accounts in order to examine existing gaps with reference to the aforementioned PSUT and AAT. Based on this analysis, a detailed list of requirements for the new water accounts was drawn up. In a next step, in order to meet these requirements, modified or new calculation methods were developed, combined with corresponding investigations regarding adequate data sources. The second chapter of this final report focuses on presenting the new calculation methods to be applied for the compilation of German water accounts, concentrating on main innovations, including their benefits, data sources, calculation methods and possible limitations as well as problems that remain unsolved.

Another project goal was to recommend the publishing of water accounts annually, instead of every three years as has been the case until now. The challenge here is that water statistics, as the main data source for water accounts, will currently continue to be available with a three-year reporting frequency only. It was therefore necessary to examine and develop suitable methods for estimating values for interim years. Chapter 3 discusses the development of these methods, the model eventually chosen and its technical implementation as well as limitations of the method.

A further project objective relates to achieving a higher degree of process automation in the compiling of water accounts by implementing the calculations, including the annual estimation, by means of SAS Analytics Software, whereas the current German water accounts have been conducted in Microsoft Excel. An overview of this implementation is provided in section 2.15.

Some results from the implementing of the new water accounts are briefly described in chapter 4, including the filled cells for the PSUT, the asset table, and an additional format created for the national publication. Finally, chapters 5 and 6 give an overview of still unsolved problems as well as potential for optimisation, and summarise findings and achievements from our project work.

2 Main innovations of the German water accounts

Chapter 2 of this report presents the different main developments implemented in the redesigned German water accounts. This part provides insights about the new structure and scope of reporting items of the redesigned water accounts. Starting with section 2.2, each of the following sections describes one of the main methodological innovations, outlining the initial situation, the reasons for methodological adjustments or innovations in the redesigned accounts, and a detailed description of the new calculation approach, as well as limitations that may potentially remain.

2.1 Expanding the scope of reporting items to PSUT and AAT

A noteworthy innovation of the redesigned German water accounts is that we set the structure and level of detail of the aforementioned PSUT and AAT as a priority objective for the scope of the reporting items. This represents a significant expansion when compared to the current German water accounts, as the reporting items of AAT did not form part of it at all and only parts of the reporting items contained in the PSUT have been published by the current German water accounts. To illustrate the planned scope of reporting items of the redesigned German water accounts, depictions of all three tables are shown below (Table 1 to Table 3).

Table 1 and Table 2 show the physical supply and use tables, based on the concept of the SEEA-CF. Both tables have an identical layout, with the columns representing the using or supplying entity and the rows organising the water and wastewater flows into five sections. Minor differences arise only in the level of detail of rows and columns, allowing for additional information value. By definition, supply and use have to be balanced out, although this does not apply for the individual cells but only for the final columns displaying the total supply and total use volumes of the corresponding water and wastewater flow positions.

In contrast to the PSUT, Eurostat's proposal to use the AAT (Table 3 below) describes additions as well as returns to a country's water stocks. In contrast to the PSUT, the AAT does not require a balance of additions and returns and is therefore an instrument for recording total changes in German water stocks. The main source of data for the AAT is the 'Joint Questionnaire on Inland Waters' (JQ-IW), being part of a series of OECD/Eurostat questionnaires on the state of the environment. In Germany, the JQ-IW comprises data from water statistics and from the 'Bundesanstalt für Gewässerkunde' (BfG, Federal Institute for Hydrology). The BfG provides additional data on precipitation, inflow from other territories, actual evapotranspiration, and outflow to other countries and the sea.

Since all new developments in the redesigned German water accounts are based on the structure of these tables, for better illustration, the new developments described in sections 2.2 to 2.12 have been assigned numbers and noted in the corresponding cells of Tables 1 to 3. The main subjects of the new developments as they are dealt with in the following sections are:

- Small companies and small industries
- Private sector
- Private households
- Exports and imports of water in products
- Soil water
- Irrigation water
- Water use in livestock farming
- Concept of residence
- Discharge of water to natural water resources
- Accumulation column

Blank cells indicate either that these values can be reported directly with the information provided in the corresponding water statistics tables without further computations, or that these are calculated as a sum of previously populated cells. In addition, the colour highlighting of cells in the PSUT helps to provide more detailed information on filling requirements:

- Dark grey: Positions not relevant for German water accounts
- Black: Cell locked per SEEA-CF definition
- Green: Additional filling, deviating from the SEEA-CF proposal
- Red: No data can be provided, i.e. positions still missing due to lack of data availability

Table 1:
SEEA-CF supply table: overview of new implemented methodologies (numbers) and information on requirements for data provision (colours)

SEEA-CF Supply Table	Industries (by ISIC category)							Households	Rest of the world	Flows from the environment	Total supply
	1-3	5-9	10-33	35	36	37	38-99		Imports		
(I) Sources of abstracted water											
Inland water resources											
Surface water										6) 7)	
Groundwater										3) 6) 7)	
Soil water										5)	
Total											
Other water sources											
Precipitation										3) 6) 7)	
Sea water											
Total											
Total supply abstracted water											
(II) Abstracted water											
For distribution							2)		4)		
For own use	6) 7)							3)			
(III) Wastewater and reused water											
Wastewater											
Wastewater to treatment	1) 7)	1)	1)	1)			1) 2)	3)			
Own treatment							2)	3)			
Reused water produced											
For distribution											
For own use											
Total											
(IV) Return flows of water											
To inland water resources											
Surface water	6)						2)	3)			
Groundwater					8)			3)			
Soil water	1) 6)	1) 6)	1) 6)	1) 6)	6)	6)	1) 2) 6)	3)			
Total							2)				
To other sources											
Total return flows											
of which: Losses in distribution											
(V) Water consumption											
Evaporation of abstracted water	1) 6) 7)	1)	1)	1)			1) 2)				
Transpiration	1) 5) 6)	1) 6)	1) 6)	1) 6)			1) 2) 6)	3) 6)			
Water incorporated into products	1)5)6)7)	1) 6)	1) 6)	1) 6)			1) 2) 6)	3) 6)	4)		
Total supply											

Irrelevant for the German water accounts
Cell locked by SEEA definition
Additional filling, deviating from the SEEA-CF proposal
No reliable values possible - missing entries

1) Small companies and small industries
2) Service sector
3) Private households
4) Exports and imports of water
5) Soil water
6) Irrigation water
7) Livestock farming
8) Discharge of water to natural water resources

Table 2:
SEEA-CF use table: overview of new implemented methodologies (numbers) and information on the requirement of data provision (colours)

SEEA-CF Use Table	Industries (by ISIC category)							Households	Accumulation	Rest of the world	Flows from the environment	Total supply
	1-3	5-9	10-33	35	36	37	38-99			Exports		
(I) Sources of abstracted water												
Inland water resources												
Surface water	6) 7)						2)					
Groundwater	6) 7)						2)	3)				
Soil water	5)											
Total							2)					
Other water sources												
Precipitation	6) 7)						2)	3)				
Sea water							2)					
Total							2)					
Total supply abstracted water							2)					
(II) Abstracted water												
Distributed water	1)	1)	1)	1)			1)			4)		
Own use	6) 7)						2)	3)				
Total							2)					
(III) Wastewater and reused water												
Wastewater												
Wastewater received from other units						7)						
Own treatment							2)	3)				
Reused water produced												
Distributed reuse												
Own use												
Total												
(IV) Return flows of water												
Returns of water to the environment												
To inland water resources											3)5)6)7)8)	
To other sources												
Total return flows												
(V) Water consumption												
Evaporation of abstracted water											1)3)6)7)	
Transpiration											1)3)5)6)	
Water incorporated into products										4)		
Total use												

- Irrelevant for the German water accounts (grey)
- Cell locked by SEEA definition (black)
- Additional filling, deviating from the SEEA-CF proposal (green)
- No reliable values possible - missing entries (pink)

1) Small companies and small industries
2) Service sector
3) Private households
4) Exports and imports of water
5) Soil water
6) Irrigation water
7) Livestock farming
8) Discharge of water to natural water resources

Regarding the AAT (Table 3), three rows are influenced by the new implementations: ‘returns’ as a sub-item of the additions and ‘abstraction’ as a sub-item of the reductions in stocks are directly filled with values from the new water accounts. Moreover, the row ‘evaporation and actual evapotranspiration’ as reported by the BfG has to be reduced by the value of transpired soil water by plants to avoid double counting. The other values are provided by the BfG and are included without modification.

Table 3:
Eurostat asset accounts table: overview of new implemented methodologies (numbers). Data for cells highlighted in red are provided by the 'Bundesamt für Gewässerkunde (BfG)' [Federal Institute for Hydrology]

Eurostat – Physical asset account for water resources	
Additions to stock – total	
Returns	1) 2) 3) 5) 6) 7)
Precipitation	
Inflows from other territories	
Reductions in stock – total	
Abstraction	2) 3) 5) 6) 7)
Evaporation and actual evapotranspiration	5)
Outflows to other territories	
Outflows to the sea	
Balance: additions – reductions	

1) Small companies and small industries
2) Service sector
3) Private households
5) Soil water
6) Irrigation water
7) Livestock farming

Additional filling, deviating from the SEEA-CF proposal
No reliable values possible - missing entries

The following methodology sections set out in more detail which rows of the PSUT and the AAT are influenced by the new calculation method. For the PSUT the rows comprise:

- (I) Sources of abstracted water
- (II) Abstracted water
- (III) Wastewater and reused water
- (IV) Return flows of water
- (V) Water consumption

Additionally, the columns of the PSUT classify the different users and suppliers, including:

- Industries
- Households
- Accumulation (use table only)
- Rest of the world
- Environment

The reporting item 'industries' is further broken down according to the ISIC (International Standard Industrial Classification) categorisation of economic activities (United Nations, 2008), including:

- Sections, represented by a capital letter (A-U)
- Divisions, represented on a 2-digit level (01-99)
- Groups, represented on a 3-digit level (011-990)
- Classes, represented on a 4-digit level (0111-9900)

ISIC and NACE are fully compatible up to the 4-digit level. The SEEA-CF proposal of the PSUT is confined to the 2-digit division level. We aim to provide the German water accounts on a partially more detailed level. Depending on the economic sector, as well as on whether the reporting year is based on water statistics data or on the annual estimation, different classification levels can be reported.

The simplified AAT proposal from Eurostat includes only the following two main parts and little further row-wise disaggregation:

- Additions to stock – total
- Reductions in stock – total

2.2 Small companies

2.2.1 Initial situation

In accordance with the 'Umweltstatistikgesetz (UStatG)' (Environmental Statistics Act), water statistics authorities conduct data collections on public (WSP) and non-public (WSNP) water supply and wastewater disposal. The breakdown of industries in the WSNP is, according to the NACE classification, for economic activities in the European Union. However, there is a cut-off limit for respondents. Only big companies or rather companies with a large water consumption that meet at least one of the following requirements are obliged to report their data for the WSNP:

- Own water abstraction of at least 2,000 m^3 per year or
- Discharge of at least 2,000 m^3 wastewater per year or
- External water purchase of at least 10,000 m^3 per year

In this report, companies that do not meet at least one of these criteria are also referred to as 'small companies', representing companies with a presumably minor degree of water use. There are no imputations or extrapolations for these small companies in water statistics, thus their respective volumes of water use and wastewater production are not accounted for in the WSNP. However, in order to provide sector-specific information relating to water flows, water accounts data on the water usage of companies needs to be based on WSNP, since they are the only data source classified according to NACE.

Because one typical objective of environmental-economic accounts is to display a complete picture of water use in the German national economy, in the old German water accounts calculations an estimation of the respective water volumes of small companies was already in place. The volume of external water purchase on the part of small companies was estimated separately by economic sector and, for compiling the overall water accounts, then added to the known volumes of water purchases as reported by water statistics in the WSNP. The estimation was based on the assumptions that small companies can be equated with companies with fewer than 20 employees and that water use is proportionate to revenue. In detail, the share of revenue of companies with fewer than 20 employees in the total revenue of the corresponding economic sector is calculated and in a further step allocated with the volumes of water use recorded in the WSNP. For example, for economic sector C 10 (manufacture of food products) in 2016 companies with fewer than 20 employees show a revenue share of 6 % in the total revenue of this economic sector. The used water volumes according to the WSNP amount to 293,640,000 m^3, which leads to an estimation of 17,149,000 m^3 additional water for the C 10 small companies in 2016.

We decided to revise the current method, because the assumption of a correlation between the number of employees, revenue and water usage does not seem very plausible, but has rather been used as an auxiliary quantity to obtain a rough estimate in the absence of a more feasible alternative approach.

2.2.2 Data sources

Statistisches Bundesamt Deutschland (StBA, German Federal Statistical Office)

- Water statistics: Non-public water supply and wastewater disposal (Fachserie 19 Reihe 2.2)
- Water statistics: Public water supply and wastewater disposal (Fachserie 19 Reihe 2.1.1)
- Business register system: Number of companies and number of employees per economic sector

2.2.3 New calculation method

Calculating a benchmark for the amount of water used by small companies

In two separate publications, the German water statistics provide data on external water purchase of non-public companies (WSNP) as well as on public water supply to economic consumers (WSP). However, there is an imbalance between these two values, indicating that public suppliers transfer more water to economic consumers than the non-public economies report to the German water statistics. Table 4 provides an example of the two mentioned water volumes and the resulting difference between public water supply and non-public purchase. It is plausible that this difference, at least to a great extent, represents water purchase of small companies not accounted for in the WSNP. Thus, and in consultation with the colleagues from water statistics, we decided to use this difference as a benchmark for the unaccounted water use of small companies in the WSNP.

Table 4:
Example for unbalanced water volumes of non-public purchase of public water and public water supply to economic consumers for the year 2019

Water purchase by non-public companies (WSNP) *1,000 m³*	Public water supply to economic consumers (WSP) *1,000 m³*	Difference indicating water purchase of small companies *1,000 m³*
516,480	876,002	359,522

Source: StBA, Fachserie 19 Reihe 2.1.1 and Fachserie 19 Reihe 2.2, year 2019

Allocation of the benchmark to economic sectors

In a next step, the identified difference has to be allocated to different economic sectors (ES). In this context it has to be noted that we assume that the public water suppliers and wastewater disposal companies (divisions E 36 and E 37) do not possess any relevant share of small companies because the WSP is designed as a survey without cut-off thresholds. Therefore, these two divisions are excluded from the new small companies' calculations.

We deemed two coefficients to be especially helpful for sectoral distribution:

- [A] economic sector's share of freshwater use in total freshwater use
- [B] economic sector's share of non-surveyed companies (NSC) in all non-surveyed companies

The share of freshwater (FW) refers to the amount of used water (less discharged unused water) per economic sector relative to the total amount of used water (less discharged unused water) by all economic sectors (less water volumes of divisions E 36 and E 37). This coefficient is able to reflect the circumstance that some economic sectors have a generally higher use of water, independent of the number or size of companies in this specific sector. The level of freshwater use is calculated as:

$$[A]_{ES} = FW_{ES} / FW_{tot}$$

In this context it should also be noted that, particularly on a more detailed NACE classification level, not all economic sectors are represented in the WSNP. For these non-surveyed economic sectors, we perform an additional freshwater estimation based on the number of employees (data available in the German business register) and average water consumption per employee (available in the WSP).

Coefficient [B] can be calculated with the help of the German water statistics data and the German business register. In the WSNP not only are the used water volumes per economic sector available but also the number of surveyed companies. Along with data on the total number of companies per economic sector, available in the German business register, the sectoral number of non-surveyed companies can be calculated. The final coefficient is the result of the number of non-surveyed companies (NSC) within an economic sector, relative to the total number of non-surveyed companies out of all economic sectors (less the companies in divisions E 36 and E 37).

$$[B]_{ES} = NSC_{ES} / NSC_{tot}$$

The final water use (WUSE) by small companies (SC) is calculated using the above-mentioned difference and a combination of the coefficients [A] and [B].

$$WUSE_{SC,ES} = Difference * (0.5 * [A]_{ES} + 0.5 * [B]_{ES})$$

The weighting factors for both coefficients were, in the absence of alternative information, specified as 0.5 each. In principle these could be adjusted to account for the relative importance of one of the coefficients.

Example calculation 1:
Water use of small companies

Relevant data for economic sector C 2444 for 2019:

- Calculated water purchase difference for allocation to small companies (less water volumes for economic sector O): 300,415,000 m3
- Total freshwater use: 14,998,812,000 m3
- Freshwater use C 2444: 74,629,000 m3
- Total number of non-surveyed companies: 3,776,778
- Number of non-surveyed companies in C 2444: 34

Calculation steps:

$74{,}629{,}000\ m^3 / 14{,}998{,}812{,}000\ m^3 = 0.0000774$	Coefficient [A]
$34 / 3{,}776{,}778 = 0.0000757$	Coefficient [B]
$300{,}415{,}000\ m^3 * (0.5 * 0.0000774 + 0.5 * 0.0000757) = \mathbf{748{,}736\ m^3}$	Water use

The additional water use by small companies in the economic sector C 2444 consequently amounts to 748,736 m^3.

Calculation of corresponding wastewater volumes

Next, the corresponding wastewater volumes of the small companies need to be estimated and added to the water accounts. Since the public wastewater disposal companies cannot differentiate between wastewater (WW) supplied by private households or by economic sectors, German water statistics do not contain separate information on these items. Therefore, a different calculation method is necessary. We decided to define a coefficient for the share of water loss in freshwater use [C], reducing the used volumes of water by possible losses occurring during water use (losses in the broader sense, i.e. due to incorporation into products, evaporation, etc.). This coefficient was calculated with the help of water statistics data for every economic sector and under the assumption that the share of water losses (WL) in freshwater use is the same for surveyed companies and the small companies:

$$[C]_{ES} = WL_{ES} / FW_{ES}$$

The final additional wastewater volume produced by small companies from each economic sector is calculated as follows:

$$WW_{SC,ES} = WUSE_{SC,ES} * (1 - [C]_{ES})$$

In a further step, these additional values must be added to the already recorded volumes appearing in the non-public water statistics survey (WSNP).

Example calculation 2:
Wastewater volumes of small companies

Relevant data for economic sector C 2444 for 2019:

- Freshwater use of C 2444: 74,629,000 m^3
- Water losses in the production process of C 2444: 3,312,000 m^3
- Water use of small companies C 2444: 748,736 m^3

Calculation steps:

3,312,000 m^3 / 74,629,000 m^3 = 0.044	Coefficient water loss
748,736 m^3 * (1 - 0.044) = **715,792 m^3**	Additional wastewater

The additional wastewater of small companies in the economic sector C 2444 consequently amounts to 715,792 m3.

Allocation of estimated small companies' water volumes to the positions of the PSUT and the AAT

In the use table, in general only part (II) 'abstracted water' is significant for small companies: We assume that small companies receive their water solely from the public water suppliers. Thus, no allocation to the different sources of 'abstracted water' in part (I), like surface or groundwater, is necessary. However, in part (II) of the table ('abstracted water'), the calculated water use of small companies by economic sector has to be added to the row 'distributed water'. Our additional assumption – that small companies do not treat the wastewater by themselves but drain the whole volume to the public wastewater disposal companies – implies that they do not need to be considered in part (III) 'wastewater and reused water'. Part (IV) 'return flows of water' and (V) 'water consumption' are solely determined for the column 'environmental flows'. Since the corresponding values are calculated as a row sum from the supply table, what this implies for small companies is discussed in the next section.

In the supply table, the additional small companies' water volumes influence part (III) 'wastewater and reused water', (IV) 'return flows of water', and (V) 'water consumption'. As in the final two parts in the use table, part (I) 'sources of abstracted water' appearing in the supply table is allocated solely to the environmental column and therefore has no significance for small companies' estimation values. This is calculated by using the row sums over the different positions of industries and households. In part (III) 'wastewater and reused water', the position 'wastewater to treatment' has to be complemented by small companies' wastewater volumes.

Even though it is assumed that small companies do not have access to their own treatment of wastewater, at least some direct return to the environment in part (IV) 'return flows of water' nevertheless needs to be accounted for because of irrigation water percolating deeply into soil. Thus, the deeply percolated water volumes should not be recorded in (V) 'water consumption' but rather in (IV) 'return flows of water'.

To obtain the percolated water volumes, based on literature investigation we assume that the deep percolation coefficient has a value of 10 %. Subsection 2.7.3 ('soil water – new calculation method') gives a more detailed explanation of the composition of this share. Firstly, the proportion of irrigation water out of the total water use [D] per economic sector needs to be calculated. In a second step, this share is multiplied by the calculated water use (WUSE) of small companies to obtain small companies' overall share of irrigation water (IW).

$$[D]_{ES} = IW_{ES} / FW_{ES}$$

$$IW_{SC,ES} = WUSE_{SC,ES} * [D]_{ES}$$

Finally, the volume of deeply percolated irrigation water (DP), which represents returns to the levels of water in soil and thus to the environment, can be calculated by applying the deep-percolation coefficient to the volume of irrigation water (IW).

$$DP_{SC,ES} = IW_{SC,ES} * 0.10$$

Example calculation 3:
Irrigation water of small companies

Relevant data for economic sector C 2540 for 2019:

- Irrigation water volumes of surveyed companies in C 2540: 62,000 m^3
- Water use of surveyed companies in C 2540: 542,000 m^3
- Water use of small companies C 2540: 14,337 m^3

Calculation steps:

62,000 m^3 / 542,000 m^3 = 0.114	Share of irrigation surveyed companies
14,337 m^3 * 0.114= **1,634 m^3**	Irrigation water small companies
1,640 m^3 * 0.10 = **164 m^3**	Deep percolation volumes small companies

Therefore, small companies in economic sector C 2540 spend 1,634 m^3 on irrigation purposes and, of this volume, 164 m^3 are percolating into the soil.

For part (V) ‘water consumption’, the share of evaporation and water incorporation during the production process are calculated in the same way as with the share of irrigation water [D] derived above. The evaporated and incorporated water volumes are then calculated by multiplying the ‘$WUSE_{SC,ES}$’ by the newly derived shares.

However, it should also be noted that incorporation into products includes two aspects: first, the previously explained water incorporation reported in water statistics and, second, some of the irrigation water that is retained and incorporated into plants. For the incorporation we assume specific shares that are based on the calculations set out in subsection 2.7.3. As with the phenomenon of deep percolation, the share of incorporation is multiplied by the volumes of irrigation water. The transpired volumes can now be calculated as a residuum of the irrigation water less deep percolation and incorporation into plants. Section 2.8 presents more detailed considerations on irrigation water and related water flows.

When it comes to the AAT figure, only the position ‘return’ – as it applies to deep percolation of irrigation water into the soil – is relevant for small companies.

2.2.4 Limitations

The exclusion by assumption of their own water abstraction by small companies clearly represents a limitation on the validity of the data. Therefore, a brief calculation was performed to quantify the potential maximum error of erroneously omitting small companies’ own potential water abstraction (y) as a proportion of the total recorded water abstraction. For this calculation, it has been assumed that all non-surveyed companies (x) abstract 2,000 m^3 of water per year. 2,000 m^3 represents the cut-off threshold in water statistics which determines whether companies are legally obliged to participate in the survey or not, and thus also represents the maximum volume of abstracted water per company that is potentially unaccounted for. The following formula has been applied, whereby ‘water abstraction’ implies the combined water abstraction volumes by public and non-public companies, recorded in the WSP and WSNP:

$$y = x * 2{,}000 / \text{water abstraction} * 100$$

The maximum value of *y* in 2016 was 3.3 %, suggesting that the potentially disregarded water abstraction undertaken by small companies, compared to the previously recorded volumes of their own abstraction according to German water statistics, is at a modest level of error. In reality, this value is presumably even lower because it is unlikely that each non-surveyed company is situated just below the cut-off threshold.

2.3 Small industries

2.3.1 Initial situation

In the data collection carried out by the German water statistics authorities, the public water supply to private households includes so-called ‘small industries’. According to the same authorities, these are by definition economic entities that share their water pipes with private households and therefore their water use cannot be disclosed separately from the water use of private households by the public water suppliers. Examples would be small bakeries, butchers or hairdressing salons as well as freelancers working from their homes. Put another way, German water statistics only includes information on the joint water supply to private households and small industries. However, the objective of water accounts is to provide separate information for water and wastewater flows of private households on the one hand, and those of other economics entities like companies on the other. For this reason, the German water accounts calculations need to incorporate an estimation of the water supply to small industries.

Traditional German water accounts calculations assume that small industries are identical with the service sector, estimated independently from the German water statistics by complex calculations described in more detail in section 2.4. Afterwards, the water volumes delivered to households by the public water suppliers listed in the WSP were reduced by the estimated water usage of the service sector to obtain the final water use of private households.

New estimation methods were considered because, besides the service sector, other economic sectors also presumably comprise relevant shares of small industries.

2.3.2 Data sources

StBA

- Water statistics: Non-public water supply and wastewater disposal (Fachserie 19 Reihe 2.2)
- Water statistics: Public water supply and wastewater disposal (Fachserie 19 Reihe 2.1.1)
- Business register system: Number of companies per economic sector

External

- German Association of Energy and Water Industries (BDEW) – drinking water use in households

2.3.3 New calculation method

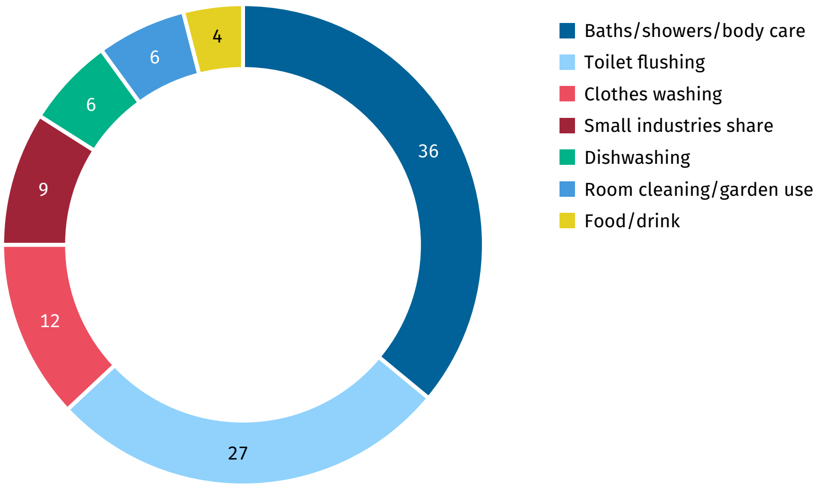
Calculation of a benchmark for the amount of water use by small industries

The water statistics do not contain further information on the share of the water volumes supplied to small industries. However, information concerning the share of water supply to small industries [F], in the water jointly supplied to households and small industries, can be found on the web page of the ‘Bundesverband der Deutschen Energie- und Wasserwirtschaft’ (BDEW) [German Association of Energy and Water Industries]. BDEW conducts an annual survey on the usage of water in private households, including small industries (“Kleingewerbe” in German). Figure 1 displays the different water usages for 2021. The benchmark for the public water supply (PWS) to small industries is calculated as follows:

$$PWS_{SI} = PWS_{PHH+SI} * [F]$$

Since a query to the BDEW confirmed that the share of small industries has been stable throughout recent years, we decided to assume a fixed value of 9 % for [F].

Figure 1:
Classification of water use by private households
in %



Source: BDEW 2021, https://www.bdew.de/service/daten-und-grafiken/trinkwasserverwendung-im-haushalt/

In 2016 the public water suppliers delivered 3,675,532,000 m^3 of water to private households and small industries. Therefore, the water volume supplied to small industries can be calculated as follows:

3,675,532,000 m^3 * 0.09 = **330,797,880 m^3**

In a next step, this water volume has to be allocated to the different economic sectors.

Definition of economic sectors with a relevant share of small industries

Unlike small companies, presumably not all economic sectors comprise a relevant share of small industries. For example, it is rather unlikely for small industries to be part of the mining sector or of public institutions like universities, schools or public administration entities. Since there is no official information available on the distribution of small industries among different economic sectors, we selected the relevant economic sectors based on our own research. Table 5 gives an overview of the selected economic sectors (ISIC class level grouped by the different sections) which we consider to contain a relevant share of small industries.

Table 5:
Number of economic sectors (class level) with relevant share of small industries grouped by the NACE classification

NACE classification Section (Division)	**Number of all economic sectors** Class	**Number of selected economic sectors** Class	**Share of selected sectors in all sectors** %
C (10-33) – Manufacturing	230	24	10
G (45-47) – Wholesale and retail trade	90	32	36
I (55-56) – Accommodation and food service activities	8	6	75
J (58-63) – Information and communication	26	8	31
K (64-66) – Financial and insurance activities	18	12	67
L (68) – Real estate activities	4	4	100
M (69-75) – Professional, scientific and technical activities	19	14	74
N (77-82) – Administrative and support service activities	33	9	27
Q (86-88) – Human health and social work activities	12	6	50
R (90-93) – Arts, entertainment and recreation	15	1	7
S (94-96) – Other service activities	19	10	53
All other divisions	141	0	0

Allocation of water volumes to the selected economic sectors

The allocation of the estimated water and wastewater volumes follows the methodology of the small companies' calculation in the previous chapter. It is important to note that the total number of non-recorded companies (for coefficient [B]) and the total amount of used freshwater (for coefficient [A]) has to be reduced to the corresponding subgroup sum of the selected economic sectors. By applying this approach, we assume that the water use of small industries and small companies follows a similar distribution, depending both on the water intensity and on the prevalence of non-surveyed companies within the different sectors.

Allocation of estimated small companies' water volumes to the positions of the PSUT and the AAT

As with the allocation to economic sectors, the allocation to sections (I) to (V) and their corresponding sub-positions of the PSUT and AAT is equal to the small companies (see subsection 2.2.3). Differences arise in the allocation to the columns of the PSUT, i.e. the economic sectors affected: as depicted in Table 5, only divisions 10-33 and 38-99 are affected by the estimations for small industries.

2.3.4 Limitation

A critical point of the aforementioned approach is the quality of information regarding the share of small industries in the public water volumes delivered to private households. Since there are no official statistics available, with the BDEW an external source has to be consulted. Although the BDEW survey does not cover all public water suppliers in Germany but only a proportion, it is presumably still a valid approach to use these data. The BDEW carries out several statistical surveys per year and even operates its own statistics portal where questionnaires can be accessed. Furthermore, a query confirmed that the share of small industries has been stable throughout recent years. If future publications reveal different values, the coefficient should be adjusted.

Since the calculation of the small industries follows the methodology of the small companies, their limitations (see subsection 2.2.4) also apply equally in this case.

2.4 Service sector

2.4.1 Initial situation

In the old water accounts calculations, the water volumes of the service sector (from NACE E 38 onwards) were estimated independently from the data provided by German water statistics. This is because until 2010 the different economic sectors within the service sector were not displayed separately by water statistics but only as one aggregate.

The old water accounts estimation for the service sector were based on various economic sector-specific indicators. Examples are the number of overnight stays or passengers for sectors related to accommodation and traffic. These indicators were then multiplied with fixed water use coefficients.

Even though these calculations provided sound estimates for the otherwise not available information on water use by the service sector – as they were once developed within an extensive, interdisciplinary project – we discontinued applying this estimation approach. Instead, we now base our water accounts on data provided by water statistics. The reason for this is that the survey data available now presumably more closely reflects the service sector's actual water use than the model-based estimation approach. Further, most of the indicators and coefficients applied in the estimation approach are now somewhat outdated and would have had to be updated if the estimation approach were to be continued (for example, to take into account increasing rates of home-office working or changing water use efficiencies due to technical innovations).

2.4.2 Data sources

StBA

- Water statistics: Non-public water supply and wastewater disposal (Fachserie 19 Reihe 2.2)
- Water statistics: Public water supply and wastewater disposal (Fachserie 19 Reihe 2.1.1)
- Business register system: Number of companies per economic sector
- Statistics on finances and taxes: civil service employees (Fachserie 14, Reihe 6)

External

- German Association of Energy and Water Industries (BDEW) – drinking-water use by private households

2.4.3 New calculation method

As there exist water statistics data for the service sector as from 2010 we decided to use these data for our calculations. Consequently, in the new German water accounts we substitute the former and above-mentioned bottom-up calculation on water use in the service sector with information provided from water statistics.

Nonetheless, the water statistics authorities' data collection on the service sector is based on the same questionnaire and survey design as those for other economic entities, since it is part of the statistics relating to non-public water supply (WSNP). Hence, the water statistics' information on the service sector is subject to exactly the same cut-off criteria for survey participation that led to the omission of so-called small companies (see section 2.2). Moreover, it is plausible that the service sector also incorporates a relevant share of small industries (see section 2.3). Consequently, the aforementioned estimations regarding small companies and small industries need to be carried out for the service sector as well.

The only exception is economic sector O – Public Administration and Defence, because its data in the water statistics are associated with greater uncertainties compared to the other economic sectors. We therefore decided to implement an additional estimation of the total water volumes for this sector. The water input is calculated on the basis of the daily water requirement in litres per inhabitant and the employees in full-time equivalents (provided by the statistics on finances and taxes) of sector O. Additionally, irrigation water volumes are added. It is assumed that the sum of staff-used and irrigation water is wholly obtained by external purchase from the public water suppliers and the abstraction of own water is excluded. Regarding wastewater, a coefficient is charged to the total water input, derived from the average water losses across the whole service sector data.

Since the entire service sector is impacted by the new calculation method, the column displaying NACE divisions 38-99 in the PSUT is affected. Regarding the AAT, the positions 'returns' and 'abstraction' are relevant.

2.4.4 Limitations

Because the water and wastewater data of the service sector are now based on the WSNP, not only the estimations for small companies and small industries but also the aforementioned limitations apply equally for this approach.

2.5 Private households

2.5.1 Initial situation

The water and wastewater volumes of private households are recorded in the WSP. However, these data have two relevant limitations. First, the reported water supply also includes water volumes of small industries. Second, the wastewater data is a combined value for private households and the economy.

To overcome these limitations, the old water accounts featured an estimation for the public water volumes supplied to small industries (see section 2.4). Additionally, we assumed and estimated a certain amount of self-abstraction by private households, based on the number of residents not connected to the public water supply, and on the average water use per resident per year. However, this approach only refers to the abstraction of groundwater and does not account for collection of precipitation by for example rain barrels or cisterns.

The second problem – joint reporting of wastewater from private households and economic sectors – has up to now been addressed by means of a wastewater coefficient, based on the share of residents connected to the public wastewater disposal. However, this approach disregards the fact that non-connected residents also produce and discharge their wastewater in one way or another.

Additional scope for improvement was detected in the calculation of irrigation water volumes used by private households. The old water accounts assumed that the irrigated area of private households amounts to 10 % of the irrigated agricultural area and that the irrigation intensity of households is equal to that of the agricultural economic sector A 01. Because this approach seemed quite arbitrary, we decided to come up with a new calculation, based on the daily water use per resident.

2.5.2 Data sources

StBA

- Water statistics: Non-public water supply and wastewater disposal (Fachserie 19 Reihe 2.2)
- Water statistics: Public water supply and wastewater disposal (Fachserie 19 Reihe 2.1.1)
- Water statistics: Structural data on water management (Fachserie 19 Reihe 2.1.3)

External

- German Association of Energy and Water Industries (BDEW) – drinking-water use by private households,
- State office for nature, environment and consumer protection, North Rhine-Westphalia (LANUV, Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen) – discharge of septic tanks' ("Kleinkläranlagen") treated wastewater

2.5.3 New calculation methods

Water use

The water supply to private households consists of external purchase and inhabitants' own abstraction of water.

External purchase takes place exclusively through the public water supply (PWS). To obtain the total water supply to private households, we simply deduct the share of small industries from the WSP data, reported jointly for households and small industries:

$$PWS_{PHH} = PWS_{PHH+SI} * (1 - [F])$$

For estimating residents' own abstraction (OA) of water, the share of residents not connected to the public water supply [G] and the public water supply (PWS) volumes going to private households are combined. [G] is calculated as the percentage of residents not connected to the public water supply out of the total number of residents. This means that we assume households unconnected to the public water supply abstract their own water and that their level of water use is identical to that of connected households.

$$OA_{PHH} = [G] * PWS_{PHH}$$

This abstraction solely refers to the environmental water source 'groundwater'. The collection of precipitation is estimated separately and in particular independently from the proportion used by non-connected residents.

In the PSUT, the external public purchase and residents' own abstraction by private households have to be recorded, unsurprisingly, in the column 'households'. When it comes to the rows, 'distributed water' and 'own use' under section (II) 'abstracted water' are relevant. Since private households do not deliver water to other entities, water distribution is solely relevant for their own external purchase and thus needs to be recorded in the use table only. The volumes distributed to private households can be found together with small industries, small companies and the rest of the economy in the column for NACE E 36. Private households' own abstraction has to be added to both households' columns of the PSUT, as well as to the abstraction row in the AAT.

Wastewater

Households may discharge their wastewater either directly or indirectly, the former implying their own treatment of wastewater and the latter implying a further separation into a centralised or decentralised flow to public wastewater disposal companies (PWW).

To estimate the indirect discharge from private households, it is crucial to first subtract the discharges of economic entities from the total discharges to the public disposals, recorded in the WSP. The economic discharges comprise wastewater volumes to public disposals of all economic units recorded in the WSNP (PWW_{WSNP}), as well as the additional estimates for small companies and small industries (see sections 2.2 and 2.3):

$$PWW_{PHH} = PWW_{Economy+PHH} - PWW_{Economy}$$

with

$$PWW_{Economy} = PWW_{WSNP} + PWW_{SC} + PWW_{SI}$$

As already mentioned, the indirect discharge of private households' wastewater to the public sewage system can be separated into a centralised and a decentralised part. The aforementioned formula only refers to the centralised collection of private households' wastewater, meaning that those residents are directly connected to the public sewage system. In terms of decentralised disposal, two different positions are distinguished in the WSP:

- Pits without outlet and not connected to central public disposals
- Other decentralised disposals

Even though these positions purport not to be part of the public disposal system, further research on these disposing methods gives grounds for assuming that most of these water volumes are nevertheless ultimately delivered to the public sewage system. Since the share [H] of this decentralised disposal (DED) out of the total disposal of private households (direct and indirect) is known from the water statistics survey on water management (also part of the WSP), the corresponding volumes can be calculated as follows:

$$DED_{PHH} = (PWW_{PHH} / (1 - [H])) * [H]$$

The total public wastewater volumes of the PHH can be calculated as the following sum:

$$PWW_{PHH,total} = PWW_{PHH} + DED_{PHH}$$

One advantage of this methodology is the establishing of a harmonised calculation for economic entities and for private households.

Example calculation 4:
Discharge of wastewater to public disposals by private households

Relevant data for the year 2019:

- total public wastewater volumes: 5,133,338,000 m^3
- wastewater volumes to public disposals of all economic units: 1,176,739,000 m^3
- share of private households' decentralised disposal: 0.2 %

Calculation steps:

5,133,338,000 m^3 - 1,176,739,000 m^3 = 3,956,599,000 m^3	Wastewater PHH
3,956,599,000 m^3 / (1-0.002) * 0.002 = 7,929,056 m^3	Decentralised wastewater PHH
3,956,599,000 m^3 + 7,929,056 m^3 = **3,964,528,056 m^3**	Total public wastewater PHH

After subtracting the public wastewater of economic entities and adding decentralised discharged wastewater, we obtain a total volume of 3,964,528,056 m^3 of public wastewater generated by private households.

A certain percentage [J] of residents who are not connected to the public wastewater disposal system operate so-called septic tanks, where on-site treatment and release of wastewater to surface or groundwater takes place. In 2016, the share of these septic tank operators was 2.8 % of the total population. The calculation of this directly discharged (DID) wastewater is based on the aforementioned calculation of the total private households' wastewater volumes and the percentage of septic tanks [J]:

$$DID_{PHH} = PPW_{PHH} / (1 - [J]) * [J]$$

Additionally, it should be noted that a certain amount of the private households' irrigation water (a detailed calculation is presented in the following section) is also directly discharged into the soil via deep percolation (DP). Therefore, the total volume of direct discharge can be calculated as follows:

$$DID_{PHH,total} = DID_{PHH} + DP_{PHH}$$

Based on a survey in North Rhine-Westphalia (LANUV NRW, 2021) we have assumed that 60 % of the directly discharged wastewater reaches surface water and 40 % groundwater bodies, whereas the deep percolation water volumes are fully assigned to the soil water.

Regarding wastewater, sections (III) 'wastewater and reused water' and (IV) 'return flows of water' need to be considered in the PSUT. In the supply table, both rows of the wastewater (to public treatment and own treatment) as well as the return to surface, ground- and soil water are affected by the households' activities. In the use table however, only the 'own treatment' of wastewater has to be considered, because private households do not receive any wastewater from other economic entities. In the use table the private households' wastewater delivered to the public sewage system is recorded in the column for NACE E 36. Equivalent to the used water volumes, the new wastewater calculations relating to direct discharge by households into the environment affect the 'returns' category in the AAT.

Irrigation water

Irrigation water volumes of private households should be considered because they are relevant for other aspects of the SEEA-CF tables, such as transpiration, deep percolation into soil water and incorporation into plants. The new methodology is once again based on the water use diagram of the BDEW (Figure 1). From this, a share for irrigation [K] can be obtained from the combined position 'room cleaning/garden use', where we assume a fifty-fifty distribution, leading to a share of 3 % for irrigation. The final irrigation water volume (IW) can be calculated in combination with the water use per resident and per day ($WUSE_{RD}$) from the WSNP:

$$IW_{PHH} = WUSE_{RD} * [K]$$

Based on this volume, incorporation into plants (IP), deep percolation into the soil (DP) and transpiration (TP) can subsequently be derived, as shown in subsection 2.2.3.

These new calculations influence section (V) ‘water consumption’ in the supply table, where the values of transpiration and incorporation into products have to be updated accordingly. Moreover, deep percolation has to be recorded in section (IV) ‘return flows of water’ as it represents a return to the soil water.

Additional water collection

The old German water accounts did not account for the collection of precipitation by private households. Also, German water statistics are not able to provide these data, because their surveys are only directed towards industrial entities, public water suppliers and public wastewater disposal companies, and not to private households.

The only external source of information about precipitation collection of households we found were two studies on the use of rainwater, carried out by the company Mall GmbH (Mall, 2010 and 2012). They provide data on the asset investment of private households of cisterns, newly installed cisterns per year and estimations on the savings of water. The latter can be equated with the collection of precipitation by private households. However, we refrained from incorporating these data directly into our calculations, because only the years 2004, 2009 and 2011 are covered and the savings of water are only estimated based on the total number of cisterns in the respective survey year.

Moreover, the aforementioned estimation of residents’ own abstraction only refers to residents not connected to the public water supply. It is reasonable to assume that connected residents also carry out additional water collection, for example from wells in their gardens. German water statistics provided data on the number of wells or springs in private households until 2004, although no additional information on the collected water volumes is available.

Despite this unclear data picture, it is important to account for and quantify the additional collection of precipitation and groundwater by private households, as otherwise the volumes of water use, wastewater, return of water to the environment and water loss do not align. More precisely, the difference between the volumes of water use and wastewater must in theory be at least as large as the sum of water returned to the environment and water consumption. Yet this condition is not fulfilled when the collection of precipitation by private households is not accounted for.

We therefore decided to build the new calculation on the additional water collection by private households on the basis of these households’ water flows, which are composed as follows:

- Water use (WUSE) based on water statistics’ data
  - Purchase of public water (less share of small industries)
  - Own abstraction (calculated based on the share of non-connected residents)
- Water consumption in beverages (based on data from the ‘Bundesministerium für Landwirtschaft und Ernährung’ (BMEL) [Federal Ministry of Food, Agriculture and Consumer Protection]
- Wastewater (WW)
  - Centralised or decentralised discharge into the public wastewater system
  - Own treatment and discharge to the environment
- Direct discharge to the environment (DIS) and water loss (WL)
  - Human transpiration and respiration (see subsection 2.12)
  - Irrigation water
  - Transpiration by plants
  - Incorporation into plants
  - Deep percolation into the soil

Rearranging the water balance, the additional water collection (AWC) by private households (PHH) can be calculated as a residual as follows:

$$AWC_{PHH} = (DIS + WL) - (WUSE - WW)$$

Example calculation 5:
Collection of precipitation by private households

Relevant data for the year 2019:

- Water use by private households based on water statistics' data: 3,508,034,530 m^3
- Water consumption in beverages: 42,182,156 m^3
- Wastewater volumes of private households: 4,038,912,027 m^3
- Private households' irrigation water volumes: 116,471,846 m^3
- Water loss through human transpiration and respiration: 28,812,510 m^3

Calculation steps:

(3,508,034,530 m^3 + 42,182,156 m^3) - 4,038,912,027 m^3 = -488,695,341 m^3	Difference water use and wastewater
116,471,846 m^3 + 28,812,510 m^3 = 154,284,356 m^3	Total environmental return / water loss
154,284,356 m^3 - (-488,695,341) m^3 = **642,979,697 m^3**	Additional water collection of PHH

Based on this calculation, private households collect an additional volume of 642,979,697 m^3.

Example calculation 5 shows that the estimated additional water collection in 2019 comprises around 140 million m^3 of water. In a next step, this difference has to be allocated to the collection of precipitation and collection of groundwater. Water statistics data show that the number of private wells has been decreasing steadily over time. The data from the Mall study show an increase in the number of cisterns (and therefore also in the amount of collected precipitation) though it seems to flatten out from around 2011. We therefore decided to set an initial proportional distribution in 2001, allocating 80 % of the additional water to groundwater and 20 % to precipitation. Until 2011, this proportion was altered annually by 3 % in favour of precipitation. So, for example in 2002, only 77 % of the additional water is allocated to groundwater but 23 % to precipitation. As of 2011 this shift has reduced to 1 %, leading to an allocation ratio of 44 % and 56 % for groundwater and precipitation by 2019.

The Mall data can also help in validating our own results. Indeed, their calculated water savings by installed cisterns is consistently on a lower level than our estimations for collected precipitation volumes. This discrepancy can be explained by the fact that the Mall survey does not cover all cisterns of private households (only single- and two-family houses with cistern volumes of 1 to 12 m^3). In addition, other possibilities for collecting precipitation, such as rain barrels and water butts, are not included in the Mall data.

A similar evaluation was conducted for the additional abstraction of groundwater: the official German 'Trinkwasserverordnung' [Drinking water ordinance] stipulates that the abstraction of water for own use must be lower than 10 m^3 a day. With this value and taking into account the number of wells from the water statistics, an upper limit was calculated that the additional groundwater volumes must not exceed.

Despite some limitations (for example by excluding evaporation losses through drying laundry, dishwashers or other wet surfaces) we assume that a complete disregard of the precipitation collection by private households would represent a more significant calculation error.

2.6 Water export and imports in products

2.6.1 Initial situation

The old water account calculations took into account (a) the water content of traded goods and (b) the export or import of water or wastewater to or from other countries by public companies. Whereas (b) is readily reported in the WSP, (a) needs to be estimated with additional calculations. Until now, these calculations only covered products consumed by private households for nutrition (beverages, meat and milk and further biotic resources) and aimed to calculate the "removal" of water by private households.

This was achieved by calculating the summed water content (by multiplying the products' weights by their individual water contents) in the aforementioned product groups for:

- domestic production
- exports
- imports

Subsequently the difference relating to water incorporated in imports and exports was added to the domestic production figures and the resulting sum equated with the water removal of private households. Consequently, the current German water accounts have not accounted for water incorporated in traded goods directly, but only indirectly via the water consumption in products used in private households. As databases for exported and imported products, statistics on foreign trade and the 'Jahrbuch der Bundesanstalt für Landwirtschaft und Ernährung (BLE)' [Annual Report of the Federal Agency for Agriculture and Food] are crucial sources.

Potential for improvement exists, because information about the water content in exports and imports should ideally be compatible with the data in the environmental-economic accounts module on economy-wide material flow accounts (EW-MFA), which among other things includes data on international material flows based on foreign trade statistics. Therefore, the new methodology aims to achieve a closer alignment of the different environmental-economic accounting modules, by solely setting the official foreign trade statistics as a starting point for the water incorporation calculation and including all listed products. Another improvement compared to the old water accounts is that the new method explicitly accounts for water incorporation into exported and imported goods and we display these separately in the PSUT.

2.6.2 Data sources

StBA

- Foreign trade statistics: Weight of exported and imported products

External

- German Insurance Association: Transport Information Service – water contents of selected products

2.6.3 New calculation method

As a new data basis for calculating the water content in exported and imported products, the German foreign trade statistics are used. We chose the breakdown that displays the products' weight in tonnes (WE) at a 4-digit level of the European product classification for foreign trade statistics ('Combined Nomenclature'). Additionally, water contents (WCONT) for individual products or groups of products (P) were investigated. Here the 'Transport Information Service (TIS)' of the German marine insurers association proved to be a comprehensive data source.

The calculation – which has to be carried out separately for exports and imports – of the traded water volumes (TWV) incorporated into goods reported at a 4-digit level can be written as follows:

$$TWV_P = WE_P * WCONT_P$$

Furthermore, foreign trade data includes information about non-responses and exemptions (based on cut-off thresholds depending on the monetary values of traded goods per company), which are only available on a 2-digit level and thus are not included in the data provided at a 4-digit level. We assume the composition of trade statistics' estimates for non-response and exemptions within a 2-digit group to be identical with the distribution of known 4-digit products in this group. As a result, we obtain the estimated proportion of the weight of each 2-digit product group subject to non-response and exemptions that can be attributed to a specific 4-digit product. Lastly, this result is once again multiplied by the water contents of the particular 4-digit product. By adding up the individual water contents of the 4-digit products, the total traded water volumes in both exports and imports are obtained.

The calculated traded water volumes of exported and imported products need to be recorded in both the use and the supply tables, in the column 'rest of the world' under section (V) 'water consumption'.

Example calculation 6:
Water incorporated in traded products

Relevant data for the water export in potatoes (group: 'vegetables, plants for nutrition'), year 2019:

- Exported weight of the product: 1,839,216 t
- Average water content of the product: 78.0 %
- Additional estimations for exported weight (2-digit group): 81,309 t
- Share of products' weight out of total 2-digit group weight: 74.29 %

Calculation steps:

1,839,216 t * 0.78 = 1,434,588 m^3	Water content of the good at a 4-digit level
81,309 t * 0.74 * 0.78 = 46,932 m^3	Water content ascribed to non-responses and exemptions
1,434,588 m^3 + 46,932 m^3 = **1,481,520 m^3**	Total water content of the good at a 4-digit level

The total water content of the exported product 'potatoes' is 1,481,520 m^3.

2.6.4 Limitations

The most relevant elements of uncertainty are presumably the coefficients for water contents, because there are no consistent values across the literature. Another weakness could be that we assume the composition of trade statistics' estimates for non-response and exemptions within a 2-digit group to be identical with the distribution of known 4-digit products in this group.

2.7 Soil water

2.7.1 Initial situation

The SEEA-CF defines the abstraction of soil water (excluding irrigation water) as uptake of water by plants, differentiating between transpired water and water contained in the final harvest product. It specifies that an estimation of soil water volumes should consider the expansion of cultivated fields, plant-specific coefficients and local effects like climate, soil texture etc.

Indications regarding the extent of soil water are somewhat ambiguous in the SEEA-CF. On the one hand, most references limit soil water to agricultural and forestry users or areas. Yet a few references mention that other users, e.g. relating to recreational activities like golf courses, also use soil water and could be considered, too.

Against this backdrop we decided to estimate the use and supply of soil water mainly for agriculture, while soil water interactions of other economic sectors and private households are only captured in the irrigation water calculations (see section 2.8).

Soil water has until now not been considered in the water accounts calculations because there are no official statistics recording these flows. The reason for this is that both in situ measurements and hydrological modelling approaches are complex and difficult to carry out. Nevertheless, given climate change and increasing summer droughts, harvest reductions or even complete failures become ever more relevant. In this context, soil water flows represent an interesting factor that will presumably gain in importance in the upcoming years. Therefore, we decided to implement a simplified calculation approach to estimate the role of soil water in Germany's water supply and use, especially focusing on agricultural (and forestry) areas and including culture-specific coefficients but neglecting local factors.

In fact, the soil water calculation also comprises the calculation of the agricultural NACE A 01 irrigation water value that will replace the older, water statistics-based values.

2.7.2 Data sources

StBA

- Agriculture and forestry, fisheries (Fachserie 3)
  - Agricultural holding with forest area (Reihe 2.1.1)
  - Vegetables survey (Reihe 3.1.3)
  - Agricultural land use – cultivation of ornamental plants (Reihe 3.1.6)
  - Survey on tree nursery (Reihe 3.1.7)
  - Cultivation and harvesting of bush fruits (Reihe 3.1.9)
  - Growing and harvesting – arable crops (Reihe 3.2.1)
  - Growing and harvesting – fruit trees (Reihe 3.2.1)
  - Growing and harvesting – grape cider (Reihe 3.2.1)
  - Aquaculture production (Reihe 4.6)
  - Survey on agricultural production methods (Reihe 5)
- Harvest and operational reports: arable crops and pasture (Qualitätsbericht 2022)

External

- German Weather Service (DWD) – monthly precipitation
- Stonestrom et al. (2003): Deep percolation through sprinkle irrigation
- Ochoa et al. (2012): Deep percolation through surface irrigation
- Colorado State University (n.d.): Water incorporation into plants
- InTeGrate: Interdisciplinary Teaching about Earth for a Sustainable Future (2018): Water incorporation into plants
- Zinknagel et al. (2017): Water requirement of outdoor vegetable crops
- Fraga et al. (2013): Coefficients for additional water in winegrowing
- Krumphuber, C. & Haider, M. (2011): Transpiration coefficients of cultivated plants
- Ehlers, W. (1998): Transpiration coefficients of cultivated crop under field conditions
- Yara GmbH (unknown): Water requirements of crop production
- Lozan et al. (2011): Water requirements of agriculture
- Riehl, G. (2021): Water requirement and transpiration coefficients of cultivated plants
- Ernst, M. (2012): Transpiration coefficients of different plants
- Zimmermann et al. (2008): Water balance of grass vegetation and forests
- Müller, J. (2013): Deep percolation under different tree species
- Englisch, M. (2016): Leaves and stock transpiration of different tree species

2.7.3 New calculation method

Since detailed explanations of the implemented calculations would be beyond the scope of this report, the following section presents only an overview of the main idea, the applied variables and their linkages, concluding with an example calculation for a clearer illustration.

The decision regarding which cultures were to be considered was based on the available data from the German agricultural statistics. These record cultivated area, total harvest yield and yield per hectare for the following cultures:

- Arable crops including meadows and pasture
- Wine
- Fruit trees
- Bush fruits
- Vegetables
- Ornamental plants
- Tree nurseries
- Forests

Because only rain-fed agriculture is relevant when it comes to soil water extraction, the amount of irrigated agricultural crops has to be calculated. Agricultural statistics provide the necessary data for doing this: overall cultivated area and irrigated area per culture and per year. Additionally, it was necessary to investigate the share of additional water, namely the volume of water that is on average supplied to the different cultures via irrigation apart from the natural occurrence of precipitation. For simplification and owing to the lack of more detailed information, the individual cultures were classified into the following groups:

- Cereals
- Leguminous and oil-bearing fruits
- Potatoes and sugar beets
- Vegetables
- Fruit trees
- Bush fruits
- Wine

Alongside this information, the water requirement of the different crops is crucial for determining the total water uptake during the growing season. In the relevant literature two different units are predominantly used in databases:

- litres per kg dry matter (DM) = transpiration coefficient
- mm per m^2

Whereas the second unit only refers to the cultivated area of the crop, the first unit also includes the yield level. For this reason, we decided to base our calculation on the first unit. Notably, this indicator shows a huge variability depending on the sources consulted (a similar problem occurs regarding information about the additional water requirement of the cultivated plants). The reason for this are the complex and manifold influencing factors for the crop water requirement, which not only depend on the crop but also on the variety, weather and soil conditions, fertilisation and other variables. To mitigate these constraints, we decided to use average values for each crop and additionally undertook a sensitivity analysis, repeating the calculations with the maximum and minimum values of each crop's water requirement.

The calculated dependent variables are shown below, with the bullet points displaying the necessary independent variables and the corresponding units shown in square brackets:

1. Rain-fed and irrigated area [1,000 ha]

   – Cultivation area [1,000 ha]
   – Share of irrigation in total crop cultivation [%]

2. Water volumes of irrigation [mil. m^3]

   – Total harvest yield [1,000 t]
   – Crop water requirement [mm/kg DM]
   – Share of additional water through irrigation in total water requirement [%]
   – Share of irrigation in total crop cultivation [%]
   – Share of irrigation losses [%]
   – Adjustment coefficient for precipitation [%]

3. Harvest yield of rain-fed and irrigated agriculture [1,000 t]

   – Total harvest yield [1,000 t]
   – Share of irrigation in total crop cultivation [%]

4. Yield in dry matter of: solely rain-fed area; rain-fed share out of irrigated areas; total out of precipitation (rain-fed + irrigated areas) [1,000 t]

   - Harvest yield of rain-fed and irrigated agriculture [1,000 t]
   - Dry matter [%]
   - Share of additional water through irrigation in total water requirement [%]

5. Use of soil water

   - Crop water requirement [mm/kg DM]
   - Yield in dry matter out of precipitation (rain-fed + irrigated areas) [1,000 t]

6. Water incorporated in harvest products [mil. m^3]

   - Harvest yields [1,000 t]
   - Norm crop moisture [%]

7. Supply to the soil water [mil. m^3]

   - Water volumes of irrigation [mil. m^3]
   - Coefficient for deep percolation [%]

8. Other irrigation water losses [mil. m^3]

   - Water volumes of irrigation [mil. m^3]
   - Coefficients for evaporation and run-off [%]

9. Transpiration of soil water [mil. m^3]

   - Use of soil water [mil. m^3]
   - Water incorporated in harvest products [mil. m^3]

To obtain the final result for the use table, all individual crop values from example calculation 7 (p. 26) have to be summed up, displaying the total abstraction of soil water in mil. m^3.

Besides its application for the use of soil water, this methodology also provides the possibility of a new and more detailed irrigation water estimation for the economic sector NACE A 01. In contrast to the old water accounts, where the irrigation volumes were simply taken from water statistics, the new calculation includes the entire amount of harvested cultivated crops and is therefore no longer limited by the cut-off thresholds for small companies. To account for climatic influences, an adjustment coefficient for precipitation during the growing season was added. This is calculated as the cumulative amount of precipitation in the months April to September in the relevant year, in proportion to the amount of precipitation in the same period for the long-term average of 1961 to 1990. Data on monthly precipitation in Germany are provided by the 'Deutscher Wetterdienst' (DWD) [German Weather Service]. This coefficient increases irrigation water volumes for years with lower precipitation amounts than the long-term average (coefficient > 1) and decreases irrigation water volumes for years with higher precipitation amounts than the long-term average (coefficient < 1). As a final step, the total irrigation water volumes are allocated to the different water resources to identify the origin of water abstraction. It is assumed that irrigation water is solely gained by own water abstraction.

For the determination of the supply or return of water into the soil, it should be noted that the PSUT according to the SEEA framework do not consider water flows within nature. Therefore, precipitation on agricultural and forestry areas needs to be considered only when this water is used by plants cultivated for economic reasons. Precipitation percolating into the soil is not recorded as a supply. With reference to this concept, the only supply to the soil water represents the deep percolation of irrigation water in the section (IV) 'return flows of water', as this flow originates from economic entities.

The calculation consists of simply adding up all irrigation water volumes and multiplying this sum by a deep percolation factor. Literature research reveals that sprinkle irrigation shows deep percolation coefficients of between 8 to 16 % (Stonestrom et al., 2003), whereas drip irrigation shows a very wide range from 5 to 30 % (Kranz, n.d.). Therefore, the coefficients were set to 10 % for sprinkle and 10 % for drip irrigation. Depending on the crop, different shares of the irrigation systems and thus different deep percolation coefficients are assumed. For example, regarding the arable crops we assume a share of 95 % sprinkle and just 5 % drip irrigation.

The other losses of irrigation water are discussed in detail in the following section (2.8).

Because these soil water calculations are limited to the agricultural cultivation of plants, in the PSUT only the column representing the NACE divisions 1-3 needs to be considered. Regarding the supply table, the deep percolation to soil water in section (IV) ‘return flows of water’, as well as the calculated transpiration and incorporation into products in section (V) ‘water consumption’, have to be integrated. In the use table, we have to include the abstracted soil water in section (I) ‘sources of abstracted water’.

Example calculation 7:
Soil water use

Relevant data for water use of winter wheat, year 2019:

- Total harvest yield: 22,756,000 t
- Share of irrigation: 1.7 %
- Share of additional water: 15.0 %
- Dry matter: 86.0 %
- Water requirement: 492 mm/kg DM

Calculation steps:

22,756,000 t * 0.017 = 386,852 t	Harvest yield due to irrigation
22,756,000 t - 386,852 t = 22,369,148 t	Harvest yield solely out of rain-fed winter wheat
386,852 t * 0.860 * (1 - 0.150) = 282,789 t	Rain-fed dry matter out of irrigated areas
22,369,148 t * 0.860 = 19,237,467 t	Dry matter out of rain-fed agriculture
19,237,467 t + 282,789 t = 19,520,256 t	Total dry matter of precipitation (rain-fed + irrigation)
19,520,256 t * 492 mm/kg DM	
= 9,603,965,952 m^3 = 9,604 mil. m^3	Soil water withdrawal based on mm/kg DM

In 2019 the cultivation of winter wheat withdrew about 9,600 mil. m^3 water out of the soil.

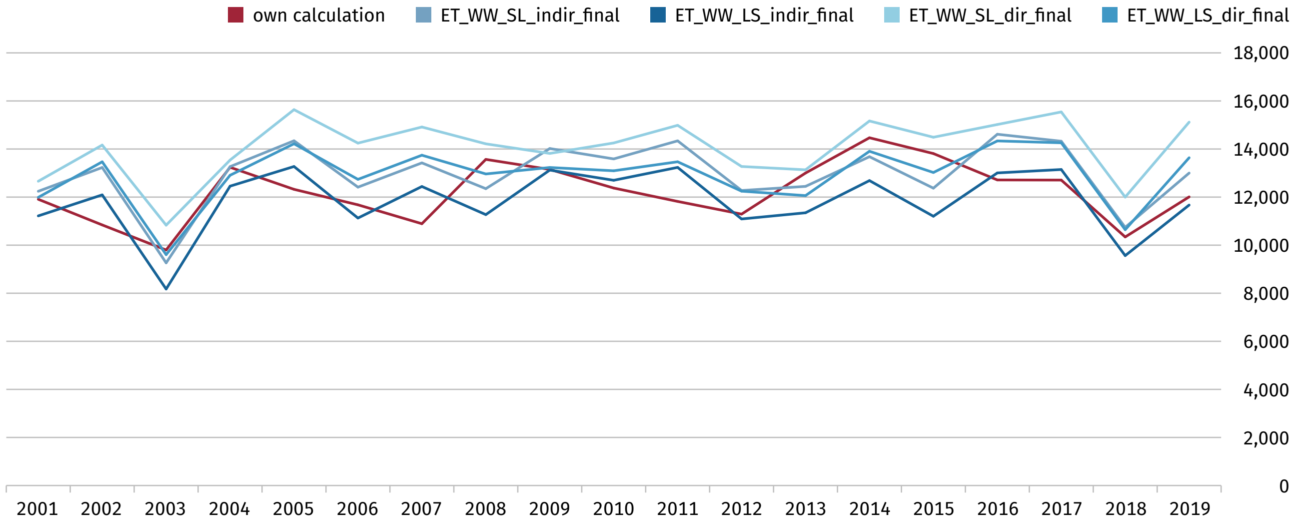
2.7.4 Limitations

As reporting on soil water represents an entirely new implementation without direct statistical survey information, several assumptions had to be made.

Firstly, we are not capable of calculating the actual evapotranspiration of agricultural fields. While at least average culture-specific coefficients and an adjustment for annual precipitation regarding the irrigation water volumes are considered, the influence of local and climatic factors is not within the scope of this project.

Nevertheless, we conducted at least a partial evaluation for winter wheat, representing one of the major cultivated crops in Germany. The German Weather Service (DWD) provides a wealth of data on actual evapotranspiration, including – besides grass-related evaporation – data for a few crops, such as winter wheat. These feature four different values, distinguishing between two calculation methods (direct and indirect) and two different soil types (loamy sand and sandy loam). A comparison in time of our calculations with the four approaches of the DWD are shown in Figure 2. Even though there are some larger deviations (e.g. in 2002, 2005, 2007 and 2011), the main trend seems to follow the trajectory of the DWD series relatively closely.

Figure 2:
Comparison between our values for winter wheat (based on yield and transpiration coefficients) with actual evapotranspiration data from the DWD
Transpiration in mil. m³



Another problem is the relatively scarce data on irrigation amounts and shares with reference to the different cultures. The official StBA survey on agricultural production methods includes information on irrigated area for the following cultures:

- Cereals for the production of grain
- Potatoes
- Sugar beets
- Legumes for the production of grain
- Oil seeds for the production of grain
- Vegetables and strawberries in outdoor cultivation

Beside the fact that the culture classification is rather rough, the survey was published only in 2010, which might imply that these data are outdated by now. Nevertheless, a new survey with data for 2022 is planned, offering the possibility of updating our coefficients. When it comes to the three-year rhythm, official data on irrigation are only available for the total irrigated area and for the share of sprinkler or drip irrigation.

Since the importance of irrigation will most likely increase in future, it can also be assumed that a more detailed recording of values might become available at some time.

Water requirement values reveal considerable variance within a specific culture, depending on the sources consulted. We therefore opted to work with average values, complemented by a sensitivity analysis displaying the potential minimum and maximum values and giving at least some indication of the accuracy of the estimation. For some culture varieties no information on their water requirement could be found. In these cases, values of similar cultures were assumed. For example, there are no values readily available for summer barley and we therefore assume that the values for winter barley are comparable and can therefore be applied to summer barley.

In general, this methodology should be deemed a rather rough estimation. Even though we do not consider the actual evapotranspiration or local effects, the integration of culture-specific water requirements and irrigation represent factors with a marked influence on water withdrawal. In combination with the two different water requirement approaches and the deduced sensitivity analysis, we nevertheless consider the estimation to be a reasonable one.

2.8 Irrigation water

2.8.1 Initial situation

As already mentioned in some previous sections, irrigation water is related to several data compartments of the PSUT. Obviously, it is one of the determinants of agricultural water use and also of several other economic sectors, albeit to a minor extent. Regarding the supply side, irrigation water needs further considerations because detailed examination of its flow in nature reveals four possible pathways:

- Incorporation into plant tissue
- Transpiration and release of water vapour to the atmosphere
- Deep percolation and return to the soil
- Run-off into surface water

The old German water accounts classify the whole irrigation volumes in terms of both water consumption and water loss. With reference to the above pathways, water loss would only apply in the case of transpiration, because water vapour is of no immediate value for the economy once it enters the atmosphere, as well as for its incorporation into plants. But we believe that the other pathways should not be neglected, even though they represent only a small percentage of the “destinations” of the irrigation volumes.

2.8.2 Data sources

External

- U.S. Department of Energy: Deep percolation through sprinkle irrigation
- Ochoa et al. (2012): Deep percolation through surface irrigation
- Colorado State University: Water incorporation into plants
- InTeGrate: Interdisciplinary Teaching about Earth for a Sustainable Future: Water incorporation into plants

2.8.3 New calculation method

The aim of our new approach is the appropriate allocation of the irrigation water volumes to the four different pathways on the supply side. This approach influences all economic entities, since the WSNP records irrigation volumes for the whole industry and we have already created a new calculation for irrigation water usage of private households (see section 2.5).

Regarding the share of water incorporated into plants (relative to plants’ entire water use) we decided to adopt a value that can be calculated with the help of the soil water estimation approach (see section 2.7), to ensure consistency in the water accounts estimations. This value is based on the amount of water stored in agricultural harvest products, relative to the total amount of water used by plants. Since this value is not fixed but calculated for each year, it is possible to account for potential weather anomalies affecting the whole country or shifting variety types and influencing total yield and yield per hectare. Research on water incorporation into plants shows a wide range of values, going from 0.1 % (Colorado State University, n.d.) to nearly 5.0 % (InTeGrate, 2018). These values can be used for evaluating our own calculated values. The volume of incorporated water into products (WP) is the result of the multiplication of total irrigation water (IW) volume by the share of incorporation [E]:

$$WP = IW * [E]$$

As already mentioned in section 2.7, deep percolation values depend on the irrigation system leading to different coefficients for sprinkle irrigation (SI) and drip irrigation (DI). The amount of deep percolated water (DP) is therefore a culture-specific combined calculation of irrigation system and the corresponding deep percolation coefficient (C):

$$DP = IW * (SI * C_{SI} + DI * C_{DI})$$

Another avenue of irrigation water loss is run-off (RO) into surface water bodies, occurring especially on steeply sloping ground and when applying too much water at once. Thus, this coefficient is set to zero for the drip irrigation, reducing the calculation as follows:

$$RO = IW * SI * C_{SI}$$

Regarding the run-off, it should also be noted that this loss is only applied to the economic sector A 01. Since the other economic sectors as well as private households do not use similarly high quantities of irrigation water, run-off events for these entities can be assumed to be negligible.

The residual quantity, obtained by subtracting incorporation, deep percolation and run-off from the total irrigation water, corresponds to transpiration by plants (TP):

$$TP = IW - WP - DP - RO$$

With this final calculation step we have come full circle and all four pathways by which irrigation water can return to the environment are covered.

These calculations have to be performed for all economic sectors, including small companies and small industries, as well as for private households.

This new calculation approach for irrigation water influences households and all the NACE divisions. In the PSUT, besides the return to soil water in section (IV) ‘return flows of water’, this also affects transpiration and incorporation into products in section (V) ‘water consumption’.

2.8.4 Limitation

The description of the calculation method reveals that the incorporation of water into plants and the amount occurring through deep percolation rely on rather restrictive assumptions.

Even though the calculation of water incorporated into plants takes into account the plants’ yield level, other factors such as the crop variety or the ratio of grain to straw can also influence the total retained volume. But since the share of water incorporated into plants is in any case in the single-digit percentage range, the mistakes committed will presumably not be decisive for portraying an overall picture of water use in the national economy.

The same applies to the share of deep percolation and run-off that, besides the types of irrigation being applied, also vary depending on soil texture, temperature, wind velocities or extent of soil coverage.

In this project it is not feasible to cover all factors that influence the four pathways of irrigation water identified above. Against this backdrop, an attempt was made to find the best possible compromise. Despite these limitations, we believe that the new calculation approach is more closely aligned to reality than simply assuming that the entire irrigation water volumes are consumed just by industry and households.

2.9 Water use in livestock farming

2.9.1 Initial situation

Official water statistics do not explicitly cover agricultural holdings with a primary focus on livestock farming. Therefore, the old water accounts contain additional estimations concerning the use of drinking water by animals and of water volumes used to clean barns or milking systems.

For the new water accounts we mainly adopted this method with only minor updates in the coefficients used, as well as some additional calculations to encompass all relevant subjects featuring in the supply and use tables.

2.9.2 Data sources

StBA

- Agriculture and forestry, fisheries (Fachserie 3)
  - Livestock of farm holdings – agricultural structure survey (Reihe 3.2.1)
  - Livestock (Reihe 4.1)

External

- Landwirtschaftskammer Oberösterreich (2019): Water requirements of animals
- Krauß et al. (2016): Drinking and Cleaning Water Use in a Dairy Cow Barn

2.9.3 New calculation method

To calculate the drinking water volumes of livestock in Germany, the numbers of livestock are multiplied by animal-specific water requirements per year. The latter are obtained from a report published by the 'Landwirtschaftskammer Oberösterreich' [Chamber of Agriculture of Upper Austria]. The total volume of drinking water consumption is then allocated to the different water resources to define the origin of the water. Surface water, groundwater and precipitation are considered as possible sources, whereas seawater is excluded. Shares of the three relevant water resources were obtained from the data in the WSNP.

To comply with the concept proposed in the SEEA-CF, not only the sources for the water quantities used in livestock farming but also the corresponding flows back to the environment have to be taken into account. Return of drinking water to the environment mainly takes place by excretory products and by transpiration. Studies on the fate of drinking water indicate that the ratio between excretion (return to the soil water) and transpiration is about 60:40 (e.g. Thorp, 2018). This applies to all animals except dairy cows as they also possess a significant amount of water in the milk they produce. With reference to Eastridge (2006), we implemented a share of 50 % for the transpiration and 25 % each for excrements and incorporation into milk.

Regarding cleaning water volumes, we incorporated the coefficients for animal-specific barn cleaning water requirements in litres per day from the old water accounts. The values are obtained from the 'Kuratorium für Technik und Bauwesen in der Landwirtschaft' (KTBL) [Association for Technology and Structures in Agriculture]. Once again, we implemented an additional estimation for dairy cows because the cleaning of milking systems also requires relatively large quantities of water. In line with Krauß et al. (2016), we set this value to 30 litres per day and animal. This is an averaged value of all the different milking systems. The total cleaning water volumes are then, like the drinking water, allocated to the different water resources.

The return of cleaning water can be split into three different pathways: we assume that the entire amount of water used for cleaning a milking system is transferred to the public wastewater system. The water used for cleaning barns on the other hand is distributed roughly equally to soil water, evaporation and to the public wastewater system.

As an example, in 2016 the water volumes in livestock farming according to the old calculation were approximately 253 mil. m^3 compared to 373 mil. m^3 with the updated approach.

2.9.4 Limitation

As the new approach is based on the number of animals rather than on the number of agricultural holdings, it is much more straightforward to estimate the water volumes used in livestock farming. Nonetheless, the animal-specific coefficients for drinking and cleaning water per day are a source of uncertainty.

An option for improvement would be to add an additional coefficient to account for years with high (summer) temperatures. According to the 'Landwirtschaftskammer Oberösterreich', drinking water values can be up to 30 % higher on hotter days.

2.10 Concept of residence

2.10.1 Initial situation

The old German water accounts are based on the concept of territory.

However, the SEEA-CF and the PWFA contain the following line: “The consumption activity of a tourist travelling abroad is attributed to the tourist’s country of residence […]” (SEEA-CF: p. 58; PWFA: p. 18). We conclude that the frameworks suggest that water accounts should be based on the concept of residence. This requires the addition of water volumes used by German residents abroad and a subtraction of volumes used in Germany by residents of other countries. These flows uses are mainly related to international tourism. Additionally, both frameworks mention that, as well as tourists, students – spending less than 12 months outside their usual country of residence – should also be considered.

However, this requirement to meet the residence principle seems to apply only to water use and not to discharge of water because, with regard to the wastewater volume, the PWFA states that “residuals (wastewater) generated by tourists will generally be attributed to local enterprises (e.g. hotels and restaurants).” Therefore, wastewater generated by tourists or students should be attributed to the visited country and its respective economic sectors. The SEEA-Water accounts provide additional information on this topic: “Even in a country with a large presence of tourists, the discharge would generally take place through resident units, such as hotels and restaurants”.

While water use is undertaken by the tourist or student (e.g. through showering or laundry), very few tourists or students directly discharge their wastewater into the environment. Normally, intermediary agents like hotels or restaurants as well as wastewater treatment facilities are involved in the discharge process and can therefore be viewed as the final users of these waste water volumes. The wastewater flows generated by tourists or students are thus covered by wastewater data reported for E 37 wastewater treatment or the hospitality industry (economic sector I).

2.10.2 Data sources

StBA

- Statistics on hospitality and tourism:
  - Tourism in figures (Fachserie 6 Reihe 7.1)
  - Travel behaviour
- Statistics on universities:
  - Students in higher education institutions (Fachserie 11 Reihe 4.1.)
  - German students abroad

External

- German Association of Energy and Water Industries (BDEW)
- Development of per capita water use
- Drinking water use in households

2.10.3 New calculation method

The Federal Statistical Office of Germany provides annual data on the travel behaviour of (A) tourists travelling from other countries to Germany and (B) German residents travelling abroad.

(A) Foreign tourists in Germany

Official statistics on the activities in Germany of tourists from other countries comprise the number of arrivals and overnight stays separately for accommodation and camping activities. To calculate the associated water use (WUSE), the number of overnight stays (OS) from accommodation (AC) or camping locations (CL) are summed and then multiplied by a daily water use coefficient [L]. The latter can be calculated with the value for daily water use per inhabitant (based on the total volumes delivered from the public supply to private households) given in the WSP [M], after subtracting the share of the small industries of 9%:

$$[L] = [M] * (1 - 0.09)$$

The final water use of foreign tourists ($WUSE_{FT}$) can be calculated as follows:

$$WUSE_{FT} = (OS_{AC} + OS_{CL}) * [L]$$

Since the water use of foreign tourists is categorised as an “export” of water, it has to be recorded in the use table as ‘distributed water’ under section (II) ‘abstracted water’ in the ‘rest of the world’ column.

(B) German tourists travelling abroad

There are no data on the total number of overnight stays of German tourists abroad but only information on the number of reported travels (RT), without any differentiation between travels abroad and travels domestically, grouped by the following travel durations:

- 1 to 3 nights
- 4 to 9 nights
- 10 or more nights

To adopt the calculations in (A), for each of these three groups, average durations were assumed:

- 2 nights (RT_2)
- 6.5 nights ($RT_{6.5}$)
- 13 nights (RT_{13})

The total number of overnight stays of German residents (OS) can then be calculated as:

$$OS = RT_2 * 2 + RT_{6.5} * 6.5 + RT_{13} * 13$$

Now, an intermediate step is necessary to calculate the share [N] of travels abroad (TA) in the total amount (T) of travels by German residents. Data on this item are also provided in the StBa’s ‘Statistics on hospitality and tourism’ report:

$$[N] = TA / T$$

The final water use of German tourists abroad ($WUSE_{GA}$) can now be calculated with the daily water use per inhabitant (excluding small industries) [L]:

$$WUSE_{GA} = OS * [L] * [N]$$

Since the water use of German tourists abroad counts as an “import” of water, it has to be recorded in the supply table as ‘distributed water’ under section (II) ‘abstracted water’ in the ‘rest of the world’ column.

Example calculation 8:
Water use of German tourists travelling abroad

Relevant data for the year 2019:

- Number of 1 to 3-night travels: 86,812,919
- Number of 4 to 9-night travels: 132,139,044
- Number of 10-night travels or more: 41,565,923
- Number of total travels abroad: 99,532,966
- Number of total domestic travels: 160,984,920
- Daily water use per inhabitant (excluding small industries): 116 litres

Calculation steps:

41,565,923 * 2 + 132,139,044 * 6.5 + 86,812,919 * 13 = 1,572,886,623	Total overnight stays
99,532,966 / (99,532,966 + 160,984,920) = 0.382	Share of foreign travels
1,572,886,623 * 116 l * 0.382 = 69,697,752,000 l = 69,697,752 m^3	Water use

The water use of German tourists abroad for 2019 is about 69,697,752 m^3. This volume is recorded as an import from the 'rest of the world' in the supply table.

Along with the data on tourist activity, the German statistics on hospitality and tourism also provide information on (C) foreign students in Germany and (D) German students abroad. As with tourists, for students we also adopted the daily water use per inhabitant (excluding small industries) [K] as a measure. Moreover, we assumed that one term comprises 100 days and that this corresponds to the length of the students' stays in Germany or abroad.

(C) Foreign students in Germany

Until 2017, the number of foreign students in Germany (St_{FG}) had only been published for the corresponding winter term. As of 2017, numbers of foreign students are available for both winter and summer term, indicating that in summer term student numbers are approximately 5 % below those for the winter term. We therefore decided to account for this reduced number of students for the reporting years before 2017, as well by using a coefficient of 1.95, to obtain the number of students for the whole year. It should also be noted that the winter term numbers relate to the following calendar year and not the current one. After presenting the implemented formula this approach is illustrated with an example. The water use of foreign students in Germany ($WUSE_{FG}$) before 2017 and as of 2017 can be calculated as follows:

Before 2017:

$$WUSE_{FG} = St_{FG} * 1.95 * [L] * 100$$

As of 2017:

$$WSUE_{FG} = (St_{FG,WT} + St_{FG,ST}) * [L] * 100$$

As for the example: to calculate students' water use in the calendar year 2019, we need information on the number of students from the winter term 2018/19 (394,665) and the daily water use per inhabitant (excluding small industries) from 2019 (116 litres).

394,665* 1.95 * 116 l * 100 = 8,927,322,300 l = **8,927,322 m^3**

Since the water use of foreign students represents an export of water, it has to be recorded in the use table as 'distributed water' under section (II) 'abstracted water' in the 'rest of the world' column.

(D) German students abroad

The numbers of German students studying abroad (St_{GA}) are similarly only available for the whole year but without information on the duration of the stay abroad. We therefore additionally assume that students spend an average of 1.5 terms abroad per year. The following formula was implemented for the water use of German students abroad ($WUSE_{GA}$):

$$WUSE_{GA} = St_{GA} * 1.5 * [L] * 100$$

Since the water use of German students abroad is an import of water, it has to be recorded in the supply table as ‘distributed water’ under section (II) ‘abstracted water’ in the ‘rest of the world’ column.

2.10.4 Limitations

Limiting factors in this approach are the assumptions about the number of students and number of days per term as well as the duration of stays of German tourists abroad. For the latter it could be especially relevant that travels abroad are presumably on average longer than domestic travels, because business trips are also included in the underlying statistics. On the other hand, the adoption of water statistics’ daily water use per inhabitant for tourists and students may not be completely precise, but more detailed information is not available.

2.11 Discharge of water into natural water resources

2.11.1 Initial situation

For return flows of wastewater to the environment, in contrast to the figures for water abstraction, water statistics do not differentiate between the different environmental water resources but only display a combined value for groundwater and surface water. Also, the old water accounts do not provide any information about which type of water resources the wastewater is being discharged into. However, the SEEA-CF supply table distinguishes between:

- Surface water
- Groundwater
- Soil water

Against this backdrop, for the new German water accounts we differentiate between the aforementioned return flows. We draw on the following ideas:

As explained in previous chapters, returns into soil water are mainly realised through deep percolation of irrigation water and to some extent by draining drinking and cleaning water of livestock farming. The corresponding equations have already been implemented (see sections 2.8 and 2.9).

Regarding groundwater and surface water, it is an axiomatic assumption that the economic sectors return their treated wastewater almost exclusively to surface water, since discharge into groundwater is strictly regulated (European Groundwater Directive 2006/118/EC).

However, the WSP as well as the WSNP account for the position ‘enriched groundwater’ within the total water abstraction of the economic sectors and the public water suppliers. We assume that a certain proportion of the abstracted (presumably unused) water is used to enrich the groundwater and thus must have been discharged into groundwater in the first place. Based on literature research on groundwater enrichment, we believe that it is mainly the public water suppliers that are involved in this process, though we could not find valid quantitative data on the water volumes.

2.11.2 Data sources

StBA

- Water statistics: Non-public water supply and wastewater disposal (Fachserie 19 Reihe 2.2)
- Water statistics: Public water supply and wastewater disposal (Fachserie 19 Reihe 2.1.1)

2.11.3 New calculation method

We assume that the discharged volume into the groundwater (DIS_{GW}) is equal to the volumes of enriched groundwater (EG) abstracted by the economic sectors (ES) and by public water suppliers (PWS), as reported in the water statistics (WSNP and WSP).

$$DIS_{GW} = EG_{ES} + EG_{PWS}$$

The calculation of return flows into soil water as well as the return into surface and groundwater by private households through septic tanks has already been dealt with in sections 2.5 to 2.8.

In the supply table of the PSUT, the position for groundwater in section (IV) 'return flows of water' can be filled combining the information from these different calculations.

2.11.4 Limitations

As we do not know the precise point in time when water for groundwater enrichment is being discharged, we simply assume that the discharged water volumes are abstracted and injected into the groundwater within one year.

2.12 Respiration and transpiration – humans and animals

2.12.1 Initial situation

As already mentioned in section 2.6, the German water accounts seek to be compatible with other modules of the environmental-economic accounts. One factor that does not feature in the old water accounts are water losses due to transpiration and respiration by humans and animals. However, these values are calculated and included in the accounting module on economy-wide material flow accounts (EW-MFA).

Systematic research within various methodological frameworks reveals that only the proposal of Eurostat on European water accounts from 2021 explicitly states that the position 'evapotranspiration' includes not only flows from plants but also respiration and transpiration of humans and animals.

2.12.2 New calculation method

Water loss through human transpiration and respiration is also one of the various pieces of information required to estimate the total precipitation collected by private households (see section 2.5). Fortunately, we can adopt the water volumes of transpiration and respiration by humans and animals directly from the EW-MFA.

In the PSUT these values have to be recorded in section (V) 'water consumption', either in the column for households or for the industrial divisions '1-3'.

2.13 'Accumulation' column in the use table

In fact, this chapter does not present a new calculation method but rather a methodological adjustment of the PSUT. As background information, it should be noted that one characteristic of the PSUT is that supply and use have to be balanced out.

In the SEEA-CF the major structural difference between the supply and the use table lies in an additional column called 'accumulation' featuring in the use table. This column includes, according to the SEEA-CF, the sum of the water incorporated into products of all economic sectors (reported in the supply table in section (V) 'water consumption').

However, we came to realise that the accounting for water incorporated in exports and imports, as well as for the purchase or discharge of German water suppliers from or to other countries, also creates an imbalance between supply and use. We therefore decided to expand the accumulation column to a 'compensation' column, balancing the differences that arise between the relevant supply and use positions affected.

As previously mentioned, the difference in water incorporated into exports and imports can be balanced in the accumulation column in section (V) 'water consumption', according to the summed incorporation of all economic sectors. As for the current state of the project, only one further accumulation cell has to be filled, balancing the disparity between purchased and delivered water to other countries in section (II) 'abstracted water', under the position 'distributed water'. To take an example, in 2016 the latter is negative, indicating that German water suppliers delivered greater water volumes to other countries than they received.

2.14 Open position

2.14.1 Reused water

The SEEA-CF PSUT ascribes values for this in section (III) 'wastewater and reused water' explicitly for 'reused water', either for distribution or for own use. This section comprises treated or untreated wastewater flows that are redistributed among the different economic sectors (or private households) for renewed use. Excluded from these figures are processed and reused water within the same company (which represents evidence of recycling processes).

Unfortunately, water statistics do not display these flows separately for the economic sectors on their division or class level, neither for suppliers nor for users. Regarding the water statistics' data on external purchases, a distinction in 'thereof (treated) waste- or cooling water' within the water user perspective is undertaken. However, it is not clearly determined that these volumes are reused because they can also be processed as non-reused wastewater, meaning they are treated and then discharged into the environment without a renewed use.

We found two examples in the relevant literature, describing the reuse of municipal wastewater for irrigation purposes or for groundwater enrichment. However, we could not find a definitive quantification of the reused volumes and data availability remains insufficient.

Given the lack of information, we currently do not see a suitable approach for providing robust estimates of reused water volumes and will thus not incorporate these reporting items in the new German water accounts.

2.15 Technical implementation

Besides improving the methodology underlying the German water accounts' estimations, the projects also aimed to achieve a greater degree of automation, reducing working hours required for the data production process and minimising susceptibility to errors. Up until now, data storage and calculation have been solely performed using Excel, generating a large number of different files that needed to be examined and updated whenever new data became available.

This automation was achieved by transferring all data sources and calculations to the statistical analysis software SAS. There the German water accounts are stored as a project, further subdivided into process flows and programs. The first part of the project comprises the import of the necessary data, either stored as Excel files or directly abstracted from the official database from the German Federal Statistical Office 'GENESIS'. It is followed by the main part, the calculation and transformation of the data to reflect the different compartments of the PSUT. The following process flows are distinguished:

- Exports and imports
- Concept of residence
- Soil water
- Water requirement for livestock farming
- Small companies and small industries
- Adjustment of data provided in the WSP and WSNP
- Private households

At the end of each process flow, a table of similar structure is created, containing all relevant information to fill in the required water position. These individual tables are then combined into one overall table that enables values from the PSUT, AAT or other publication formats to be included.

Even though the transfer from Excel to SAS entailed a considerable amount of work, we are convinced that this technical implementation will save time in the preparation of future publications and will lead to methodological improvements to our own water accounts.

Some noteworthy advantages of SAS in comparison to Excel are:

- Easier and faster calculation options for large and complex data sets
- Easier updating of data sources and coefficients, especially when these are used for several different calculations
- Adjustments in the calculations at a defined place and not in single cells which may be difficult to find in a large set of Excel files and sheets
- Structure of the whole German water accounts is recognisable at a glance
- Possibility to treat different years in different ways within the same program code
- Easier combination and merging of different data sets and tables

3 Estimation of annual data

3.1 Overview

As outlined at the beginning of this report, one goal of this project consists in developing a methodology that allows for publishing water accounts with an annual periodicity instead of every three years as has been the case up to now. The challenge here is that German water statistics, being the main data source for water accounts, are available only with a three-year reporting period. With this in mind, it was necessary to develop suitable estimation methods for estimating the values for interim years.

The yearly estimations must not be misinterpreted as any kind of prediction. They only provide a retrospective publication of the interim years between the two years covered by the water statistics. Since the latest publication of the water statistics dates to 2019, the interim years 2020 and 2021 will be published together with the year 2022 as soon as water statistics data for 2022 become available. Sections 3.2 to 3.5 give detailed explanations around the research, development and evaluation of our annual estimation of the German water accounts. For our estimation of interim years, we combine four approaches – regression analysis, coefficients, direct calculation, and indirect calculation. As a brief overview, these main approaches are outlined in the following remarks, complemented by references to the PSUT and AAT.

(A) Regression analysis

The core element of the annual estimation is a regression analysis carried out on the total water input of each economic sector. The aim of this regression analysis is to provide a benchmark, reflecting not only the evolution of water usage over time but also water requirements specific to different economic sectors, to account for possible influencing factors during interim years.

(B) Coefficients

The aforementioned economic sector-specific benchmark of the total water use serves as a starting point for further allocations into more detailed positions of the PSUT. This is done by using the top-down method with the help of coefficients derived from those years where German water statistics data are available. For example, we can derive from the total water input the volume of users' own abstraction (differentiated by water resources) or the volume purchased externally. This approach aims to construct the same water reporting items as provided by water statistics. These interim results allow us to finally apply the new calculation methods presented in chapter 2 for interim years as well.

(C) Direct calculation

Because some new implementations do not rely on water statistics, direct calculations are possible if the underlying data sources are released annually. In fact, this approach does not result in further uncertainties around the calculation results, because the calculation is equal to the one conducted for those years covered by the existing water statistics.

(D) Indirect calculation (aggregation of already estimated values)

Our last approach is to yield annual values by aggregating the other water accounts' values estimated before. This relates primarily to PSUT positions headed with the term 'total', representing row or column sums. Nevertheless, other water volumes can also be calculated using this approach, if single volumes consist of more easily assessable values in contrast to the total value. This mainly applies to public water distribution (E 36) and public wastewater disposal (E 37).

As an overview and corresponding to the new developments of the German water accounts shown in Table 1 to Table 3, Table 6 to Table 8 show the physical supply and use tables (PSUT) as well as the asset accounts table (AAT), with letters representing the relevant concept per individual cell.

Table 6:
SEEA-CF supply table: overview of the relevant concepts for the implementation of the annual data estimation (letters)

SEEA-CF Supply Table	Industries (by ISIC category)							Households	Rest of the world	Flows from the environment	Total supply
	1-3	5-9	10-33	35	36	37	38-99		Imports		
(I) Sources of abstracted water											
Inland water resources											
Surface water										C	C
Groundwater										C	C
Soil water										C	C
Total										C	C
Other water sources											
Precipitation										C	C
Sea water										C	C
Total										C	C
Total supply abstracted water										C	C
(II) Abstracted water											
For distribution	A	A	A	A	A C		A		A B		C
For own use	A B	A	A	A	A		A	A			C
(III) Wastewater and reused water											
Wastewater											
Wastewater to treatment	A B	A	A C	A	A	A	A C	A			C
Own treatment	A	A	A	A	A	A	A	A			C
Reused water produced											
For distribution											C
For own use											C
Total	C	C	C	C	C	C	C	C			C
(IV) Return flows of water											
To inland water resources											C
Surface water	A B	A	A	A	A	C	A	A			C
Groundwater					C			A			C
Soil water	A B	A	A	A	A	A	A	A			C
Total	C	C	C	C	C	C	C	C			C
To other sources											
Total return flows	C	C	C	C	C	C	C	C			C
of which: Losses in distribution					A						C
(V) Water consumption											
Evaporation of abstracted water	A B	A	A	A	A	A	A				C
Transpiration	A B	A	A	A	A	A	A	A B			C
Water incorporated into products	A B	A	A	A	A	A	A	A	B		C
Total supply	C	C	C	C	C	C	C	C			C

(A) Regression analysis + coefficients

(B) Direct calculation

(C) Indirect calculation (aggregation of already estimated values)

Table 7:
SEEA-CF use table: overview of the relevant concepts for the implementation of the annual data estimation (letters)

SEEA-CF Use Table	Industries (by ISIC category)							Households	Accumulation	Rest of the world	Flows from the environment	Total supply
	1-3	5-9	10-33	35	36	37	38-99			Exports		
(I) Sources of abstracted water												
Inland water resources												
Surface water	A B	A	A	A	A	A	A					C
Groundwater	A B	A	A	A	A	A	A	A				C
Soil water	B											C
Total	C	C	C	C	C	C	C					C
Other water sources												
Precipitation	A B	A	A	A			A	C				C
Sea water	A	A	A	A			A					C
Total	C	C	C	C	C	C	C					C
Total supply abstracted water	C	C	C	C	C	C	C					C
(II) Abstracted water												
Distributed water	A	A	A C	A	A	A	A C	B	C	A B		C
Own use	A B	A	A	A	A	A	A	A				C
Total	A	A	A	A	A C	A C	A	C				C
(III) Wastewater and reused water												
Wastewater												
Wastewater received from other units						A C						C
Own treatment	A	A	A	A	A	A	A	A				C
Reused water produced												
Distributed reuse												C
Own use												C
Total	C	C	C	C	C	C	C	C				C
(IV) Return flows of water												
Returns of water to the environment												
To inland water resources											C	C
To other sources												C
Total return flows											C	C
(V) Water consumption												
Evaporation of abstracted water											C	C
Transpiration											C	C
Water incorporated into products									C	B		C
Total use	C	C	C	C	C	C	C	C	C	C	C	C

(A) Regression analysis + coefficients
(B) Direct calculation
(C) Indirect calculation (aggregation of already estimated values)

Table 8:
Eurostat asset accounts table: overview of the relevant concepts for the implementation of the annual data estimation (letters)

Eurostat – Physical asset account for water resources	
Additions to stock – total	
Returns	C
Precipitation	
Inflows from other territories	
Reductions in stock – total	
Abstraction	C
Evaporation and actual evapotranspiration	B
Outflows to other territories	
Outflows to the sea	
Balance: additions – reductions	

(A) Regression analysis + coefficients
(B) Direct calculation
(C) Indirect calculation (aggregation of already estimated values)

data provided by the German water accounts
annual data provided by the BfG

3.2 Regression

3.2.1 Initial situation

In order to devise an annual estimation model, we first compared our available data and target structure and worked out the following relevant characteristics that might narrow down our options:

- Water statistics data is available in one out of three years
- Several economic units (NACE codes) partly show strongly deviating water requirements among one another
- The number of data points depends on the economic unit (NACE code) considered
- Over 20 different water items are needed to fill in the PSUT

Against this backdrop, we determined that our desired model should be able to include a possible time trend to display the time-series character of the data. On the other hand, we wanted to account for the different water demands of the individual economic sectors since their distinction is also a decisive element of the PSUT. We decided to focus on regression models as these allow for the estimation of a causal relationship between a dependent variable and one or more independent variables.

Next, we defined which data should be included in the evaluation process of different regression models. We decided to perform calculations only on the 1-digit NACE section level (encoded by capital letters A to U). The main reason was that for some 4- or 2-digit codes, the number of reporting units in water statistics can be low or even zero and data are kept confidential for these codes – in other words, our data basis would have been insufficient. Considering only the 1-digit level therefore aims to maximise the available number of data points per economic unit.

Regarding the time span covered, we decided to include values as of 2001. We were therefore able to rely on a maximum of seven years, i.e. 2001, 2004, 2007, 2010, 2013, 2016 and 2019 with data from water statistics.

However, not every economic sector has been surveyed from the outset by the water statistics. Economic sector A (Agriculture, forestry and fishery) as well as the whole service sector (E38 – U) are covered only from 2010 onwards. Table 9 shows a summary of the available data points per economic sector. The table additionally indicates that economic sectors T and U are not covered by the water statistics and are therefore also omitted in the annual estimation.

Here it should be noted that economic sector O – Public Administration and Defence (Compulsory Social Security) is also excluded from the annual estimation, since its water volumes are calculated independently from water statistics data based on the number of full-time equivalent employees (see subsection 2.4.3). Moreover, the estimation for economic sector E excludes public water supply (E 36) and public waste water disposal (E 37) because their values are calculated by means of a different approach (see section 3.5). Regarding economic sector A – Agriculture, Forestry and Fishing, in the regression analysis the volumes of irrigation water have been excluded as these are calculated within the scope of the soil water values.

Table 9:
Summary of available data points per economic sector on the 1-digit sector level

Economic sector (NACE 1-digit level)	Number of data points
A – Agriculture, Forestry and Fishing	4
B – Mining and Quarrying	7
C – Manufacturing	7
D – Electricity, Gas, Steam and Air Conditioning Supply	7
E – Waste Management and Remediation Activities	4
F – Construction	4
G – Wholesale and Retail Trade	4
H – Transporting and Storage	4
I – Accommodation and Food Service Activities	4
J – Information and Communication	4
K – Financial and Insurance Activities	4
L – Real Estate Activities	4
M – Professional, Scientific and Technical Activities	4
N – Administrative and Support Service Activities	4
P – Education	4
Q – Human Health and Social Work Activities	4
R – Arts, Entertainment and Recreation	4
S – Other Service Activities	4

As already briefly mentioned, a regression analysis aims to estimate the dependent variable by means of one or more explanatory variables. Both PSUT and water statistics cover quite a large number of reporting items. However, we decided to make total water input (consisting of own abstraction plus external purchase) of each economic sector the only dependent variable. Reasons for this decision are, on the one hand, that each economic sector definitely pursues at least one of the two activities ‘abstraction’ and ‘purchase’ and that this hence ensures that data points for water input are available in every reporting year covered by water statistics. On the other hand, total water input provides an economic sector-specific benchmark that serves as a good starting point for deriving further reporting items in water accounts. This calculation according to the ‘top-down’ principle is described in detail in subsection 3.2.4.

The next step comprised identifying suitable independent variables made available on an annual basis. In this case, ‘suitable’ means that these variables should be plausible predictors for changes due to external factors in the total water input of a specific economic sector on a year-by-year basis. These independent variables can be distinguished into two different classes. Firstly, there are economic indicators that are equally valid for all economic sectors. These variables are:

- Number of companies,
- Number of employees
- Hours worked
- Output value
- Gross value added
- Revenue

Secondly, there are economic sector specific independent variables which have a logical link to specific sectors only. A summary of these variables is provided in Table 10. Note that it was not possible to find specific indicators for all economic sectors.

Table 10:
Summary of economic sector specific independent variables tested in the selection process of a regression analysis model

Economic sector (1-digit level)	Potential Regressors
A – Agriculture, Forestry and Fishing	Precipitation, mean temperature, cultivated area, irrigated area, yield, area protected agriculture
B – Mining and Quarrying	Material consumption, energy consumption, investments, quarried volumes
C – Manufacturing	Material consumption, energy consumption, electricity costs
D – Energy Supply	Natural gas production, electricity production, heat production, fuel input, energy production
E – Waste Management and Remediation Activities	Waste volumes
F – Construction	Construction completions, Number of built accommodations
G – Wholesale and Retail Trade	Cost of sales, retail space
H – Transportation and Storage	Number of air, ship and train passengers
I – Accommodation and Food Service Activities	Number of overnight stays, opened lodging establishments, purchase of operating materials
P – Education	Number of pupils, trainees and students
Q – Human Health and Social Work Activities	Hospital patients, surgeries, humans in nursing homes, medical costs

3.2.2 Model selection and evaluation process

The framework and data sources set out in subsection 3.2.1 served for the testing of various regression models. Each model was tested and evaluated with regard to the following four aspects:

- Integration of a trend component
- Integration of independent variables (predictors)
- Ability to handle small numbers of observations
- Ability to handle missing data in the dependent variable

Since the annual estimation should be integrated into the whole data production process, it has also been implemented in the SAS software. Table 11 presents a summary of all models tested, the corresponding SAS procedures and their suitability according to the aforementioned evaluation criteria. Each model was tested separately with each economic unit and, if possible, with each predictor variable.

Table 11:
Tested models and evaluation results

Model specification	SAS procedure	Trend component	Predictors	Number of observations	Missing values
Interpolation of time series	Proc EXPAND	☐	☐	☑	☑
Processing of transactional data	Proc TIMESERIES	☑	☐	☑	☑
Linear regression	Proc REG	☐	☑	☑	☑
Unobserved components model	Proc UCM	☑	☑	☐	☐
Auto-regressive integrated moving average	Proc ARIMA	☑	☑	☐	☑
State-space model	Proc SSM	☑	☑	☑	☑

The first two procedures are especially suitable for revising and redesigning time series data. However, they are not suitable for our case, because ‘Proc EXPAND’ performs a simple interpolation regardless of any trend or predictor variables. ‘Proc TIMESERIES’ allows for trend-related or seasonal components but, again, predictor variables cannot be included.

‘Proc REG’ is a general-purpose tool for running linear regressions. Economic sector-specific predictor variables can easily be incorporated and missing values in the dependent variable are estimated by means of the regression equation. Nevertheless, there is no possibility to define a trend component and in many cases the values estimated by the regression equation showed strong deviations from the actual values calculated from the water statistics’ data.

Models with the option of including a trend component as well as predictor variables are the ‘Unobserved components model’ (UCM), the ‘Auto-regressive integrated moving average’ (ARIMA) model and the ‘State-space model’ (SSM). ARIMA models were first introduced by Box and Jenkins (1970) and aim to predict a value in a time series as a linear combination of its own past values as well as past errors. Further information on ARIMA models, also known as Box-Jenkins models, is provided by Williams and Lester (2003). The UCM decomposes a time series into several components like trend, season or cycles that are presumed to represent important features that explain the probable (future) behaviour of a particular time series. For more detailed information on UCMs, see Harvey and Peters (1990). The problem we faced with ARIMA was that the procedure requires, at least in SAS, a minimum of six observed values. In our case this would only apply to economic sectors B, C and D. Furthermore, the ‘ESS (European Statistical System) guidelines on temporal disaggregation, benchmarking and reconciliation’ (Eurostat, 2018), state that ARIMA should be preferred for making predictions or in cases where no explanatory variables are available. ‘Proc UCM’ presumably also encountered the problem of limited data availability because, in our tests, the model did not converge for some economic sectors and consequently was unable to provide estimation results.

The only model we found that seemed to fulfil all our requirements was the State-space model, represented by the procedure ‘Proc SSM’ in SAS. As this model was also finally implemented and used for the annual estimation, it is described in more detail in the following subsection.

3.2.3 State-space model

General aspects of the State-space model

The State-space model (SSM) approach was first introduced by Harvey in 1989. Nowadays, detailed literature concerning experiences, further developments and the implementation in SAS of the SSM are readily available, for example from Durbin and Koopman (2012), Pelagatti (2015) and Selukar (2015). As a comprehensive explanation of the SSM would be beyond the scope of this report, the following paragraphs focus on its main characteristics to support our choice of model.

Like ARIMA and UCM mentioned above, the SSM belongs to the class of ‘structural time series models’, aiming to decompose the time series under consideration into a set of unobserved components. Unobserved components are e.g. trend, seasonal or regression components and are stored in the so-called ‘state variables’. The SSM approach assumes that the observations recorded in a time series are determined by the temporal development of these state variables. In our case that would mean that the total input of water in a single economic sector is dependent on unobserved components like trend and season that change over time and therefore also influence the (annual) total water input. The observations (in our case the total water input) can also be a directly observed explanatory variable.

Is it therefore necessary to define two separate equations, one to explain the evolution of the observed (dependent) variable and one to explain the evolution of the state variables. The following section provides a simple example to illustrate the mathematical principles, based on explanations by Kotzé (n.d.).

A time series is a set of observations, $\{y_1,...,y_T\}$, ordered in time that may be expressed in the following additive form:

$$y_t = \mu_t + \lambda_t + \varepsilon_t \qquad t = 1, ..., T \qquad (1.1)$$

where

- μ_t is a slowly varying component called the *trend*
- λ_t is a periodic component of fixed period called the *seasonal*
- ε_t is an irregular component called the *error*

It is then assumed that the state variables μ_t and λ_t follow an underlying process that can be described by a series α_t such that:

$$\alpha_{t+1} = \alpha_t + \eta_t \qquad \eta_t \sim \text{i.i.d.N}(0, W_\eta) \qquad (1.2)$$

Assuming a normal distribution of all variables, equations (1.1) and (1.2) can be rewritten as:

$$y_t = \alpha_t + \varepsilon_t \qquad \varepsilon_t \sim \text{i.i.d.N}(0, V_\varepsilon) \qquad (1.3)$$

$$\alpha_{t+1} = \alpha_t + \eta_t \qquad \eta \sim \text{i.i.d.N}(0, W_\eta) \qquad (1.4)$$

Equation (1.3) represents the 'observation equation', describing the relation between the observed variables $\{y_1, ..., y_n\}$ and the unobserved state variables α_t. Equation (1.4) is called the 'state equation' and reflects the dynamics of the unobserved state variables $\{\alpha_1, ..., \alpha_n\}$. Essential to the SSM methodology is that the properties of the 'α_t's are now inferred with the help of the available observations $\{y_1, ..., y_n\}$. This is rather difficult since it is assumed that the observations as well as the state variables are able to evolve over time.

It is therefore crucial to find the best estimation for the state variables. One commonly used algorithm is the 'Kalman filter', first introduced and described by Kalman (1960) and later by Kalman and Bucy (1961). According to Durbin and Koopman (2012), the Kalman filter provides optimal results for the state variables as well as for the observation equation. In general, the Kalman filter allows us to calculate three different types of inference from our data:

- Prediction: forecasting of *subsequent* values of the state variables
- Filtering: estimation of *current* values of the state variables
- Smoothing: estimation of *past* values of the state variables

Regarding the annual estimation of the German water accounts, in particular the 'smoothing' function of the Kalman filter is interesting for us, because it offers the opportunity to estimate the missing interim years. This is done based on the assumption that the values for the state variable α_{t+1} are largely related to the observation from a previous period y_t. The 'smoothing' procedure therefore aims to estimate the past (and in our case partly missing) state variables considering all available observation data. Given equations (1.3) and (1.4), the estimation of the state variables in the missing interim years allows us to subsequently estimate the observation variable. In this context it should be noted that estimations generated by 'smoothing' may change for the whole time series when new observation values become available.

An additional aspect of the calculation process is that only missing values are estimated, whereas existing values remain unchanged. This is an important distinction from other model approaches, such as linear regression using Proc REG.

After this brief introduction to the State-space models and Kalman filters, the following section discusses how they can be applied to our data.

Application of the SSM approach to our data

As already mentioned, our observation data y_t comprises the total water input, consisting of the sum of own abstraction and external purchase of water. Since we intend to complement the estimation of the observation variable by an economic sector-specific independent variable (e.g. working hours, revenue, quarried volumes etc.), the observation equation is extended as follows:

$$y_t = \alpha_t + X_t\beta_t + \varepsilon_t \qquad \varepsilon_t \sim \text{i.i.d.}N(0, V_\varepsilon), \qquad (1.3b)$$

where X_t denotes the fully known predictors, i.e. the independent explanatory variables, and β_t is the corresponding regression vector.

Regarding the state equation, we decided to include solely a trend component, because there is no seasonal component in the three-year data received from the water statistics. Considering the small number of observation points per economic sector it is also reasonable to reduce the number of equation parameters to the bare minimum.

In terms of the trend component, the SAS procedure 'Proc SSM' provides several different trends, whose properties can be looked up in the SAS documentation. During the evaluation process we tested our calculation with several trends:

- Linear time trend
- Random walk trend
- Local linear trend
- Integrated random walk
- Damped local linear trend
- ARIMA trend

The trends differ in their values and treatment of level and slope variance. Additionally, damped local linear trend and ARIMA trend include an auto-regressive component.

Implementation of the adjusted State-space model in SAS

We started the calculation of the SSM in SAS separately for each economic sector. Second and third grouping factors were trend and independent variables. So, for each combination of economic sector, trend and (economic sector-specific) independent variable an analysis in SAS was performed. In this case of economic sector B – Mining and Quarrying, this leads to a potential total number of 6 (trend) x 10 (independent variables) models and therefore 60 different estimation results.

However, the calculation of the first economic sectors revealed that calculations based on the independent variables 'revenue', 'gross value added' and 'output value' produced nearly identical results. For reasons of time efficiency, we thus decided to focus on 'output value' only. Another restriction was set regarding the trend component: presumably caused by the low number of observation values, model convergence failed in most cases when implementing the damped local linear trend or the ARIMA trend, as these include additional factors for the auto-regressive component that need to be estimated. The evaluation of the economic sector-specific model was therefore reduced to the remaining four trends.

Figure 3 gives an example of the SAS code used to calculate annual values for total water input for economic sector B – Mining and Quarrying. Included are the 'integrated random walk' (with the level variance set to 0) defining the state equation part and 'quarried volumes' as an economic sector-specific independent variable directly influencing the observation equation. Additionally, an 'irregular' term was specified as an error term that also affected the observation equation. All three components are combined in the 'model' statement, complemented by the 'print' option telling SAS to apply the 'smoothing' procedure. The 'output' statement creates a data set containing the estimations for the interim years as well as the unaffected values for the years with observation data.

Figure 3:
Example of the SAS code to estimate the values for total water input in the interim years for the economic sector B – Mining and Quarrying

```
proc ssm  data=Economic_sector_B plots=all  Optimizer(Maxiter=1000);
    id Year;
    trend llTrend(ll) levelvar=0;
    irregular wn;
    model water_input = Quarried volumes llTrend wn / print=smooth;
    output out=Sector_B_estimate pdv press;
run;
```

Evaluation of the different models

As previously mentioned, an initial comprehensive evaluation was conducted by comparing the different combinations of trend component and independent variables for each economic sector.

As an example, Table 12 shows a comparison between two different trends and four different independent variables for economic sector B – Mining and Quarrying. Obviously, the estimated values for a given year differ between the two trends and also between the different independent variables within one trend. Also, the choice of the independent variable seems to have more influence on estimation results than the choice between two trends.

Selection of the trend was based on the constraint that only one trend should be chosen that provides an adequate fit for economic sectors. This is to keep the estimation procedure for annual results at an adequate level of complexity. As a selection criterion we used the ‘Akaike information criterion’ (AIC) (Akaike, 1981), which is an estimator of the prediction error and therefore provides an estimator for the relative quality of several statistical models applied to the same data set. The decision criteria are defined as follows: the lower the AIC, the better the model fit. We therefore decided to work with the so-called ‘integrated random walk’, showing the lowest AIC values in the majority of the economic sectors and independent variables. It represents a special form of the ‘local linear trend’, in which both the level and the slope of the curve change with time. This variation in the level and the slope is controlled by the two parameters σ_1^2 and σ_2^2. Regarding the ‘integrated random walk’, the level variation σ_1^2 is set to 0 and only the slope variation is controlled by σ_2^2.

When it came to the choice of independent variable, we decided to focus on the importance of the presumed water requirement, rather than on the AIC only. When possible, economic sector-specific independent variables – like ‘quarried volumes’ for economic sector B – were preferred over general economic factors like output value. Additionally, graphical reviews were performed to detect apparent outliers or even negative values which would represent definitely implausible results.

Table 12:
Example of the annual estimation for the total water input (mil. m³) of economic sector B for two trends and four independent variables

Year	Original value	Quarried volumes	Energy consumption	Output value	Working hours
	Local linear Trend				
2001	2,425	2,425	2,425	2,425	2,425
2002		2,393	2,399	2,400	2,379
2003		2,373	2,375	2,486	2,271
2004	2,345	2,345	2,345	2,345	2,345
2005		2,328	2,357	2,270	2,398
2006		2,349	2,342	2,317	2,384
2007	2,329	2,329	2,329	2,329	2,329
2008		2,286	2,272	2,321	2,251
2009		2,212	2,224	2,077	2,301
2010	2,149	2,149	2,149	2,149	2,149
2011		2,115	2,080	2,135	2,039
2012		2,002	1,996	2,045	1,996
2013	1,894	1,894	1,894	1,894	1,894
2014		1,743	1,746	1,798	1,689
2015		1,588	1,602	1,671	1,566
2016	1,465	1,465	1,465	1,465	1,465
2017		1,419	1,400	1,446	1,324
2018		1,370	1,342	1,380	1,322
2019	1,301	1,301	1,301	1,301	1,301
	Integrated random walk				
2001	2,425	2,425	2,425	2,425	2,425
2002		2,392	2,399	2,400	2,379
2003		2,373	2,375	2,485	2,269
2004	2,345	2,345	2,345	2,345	2,345
2005		2,326	2,357	2,270	2,400
2006		2,350	2,341	2,317	2,385
2007	2,329	2,329	2,329	2,329	2,329
2008		2,287	2,272	2,321	2,250
2009		2,211	2,225	2,078	2,302
2010	2,149	2,149	2,149	2,149	2,149
2011		2,121	2,081	2,136	2,039
2012		2,004	1,996	2,045	1,997
2013	1,894	1,894	1,894	1,894	1,894
2014		1,741	1,745	1,797	1,688
2015		1,586	1,603	1,670	1,565
2016	1,465	1,465	1,465	1,465	1,465
2017		1,421	1,399	1,445	1,322
2018		1,372	1,340	1,378	1,321
2019	1,301	1,301	1,301	1,301	1,301

Additional evaluations of the SSM model specifications were performed using the following two approaches 'forecast' and 'backcast'.

Forecasts were performed, because the new data for 2019 from water statistics were only available at a later stage of the project. We therefore used the forecast option of the Proc SMM procedure to project the values for 2017, 2018 and 2019 based on water statistics data up to 2016. After receiving the new data for 2019, the projected values were compared with the genuine values.

Backcasts were defined as the omission of one single observation (therefore reducing the total number of observations) with the subsequent calculation of the SSM with the 'smooth' option. Depending on the number of available observations, three to five different backcasts could be performed per economic sector by omitting one of the observations from the water statistics time series. The estimated value of the omitted observation was then compared with the true value for this observation and the deviation was then calculated for each omitted year. The average deviation was then used as an indicator to decide which combination of trend and independent variable provides the best results for a given economic sector. Table 13 provides an example of these average deviation calculations for five different economic sectors and their corresponding specific independent variables. Percentage values represent the average deviation of the backcasted observation years from the original observation value. Taking sector B again as an example, 'employees' with an average deviation of 3 % (backcasted years: 2001, 2004, 2007, 2010, 2013, 2016) seems to create the best fit, closely followed by 'quarried volumes' and 'output value'. In general, deviations tended to be lower when a higher number of observations was available (see economic sectors B, C and D).

Table 13:
Example of backcast results for different economic sectors and independent variables, using the local linear trend

Economic sector	Independent variables and average deviation			
A – Agriculture, Forestry and Fishing	Area (vegetables)	Precipitation	Yield	Area (total)
	10%	12%	58%	304%
B – Mining and Quarrying	Working hours	Quarried volumes	Output value	Energy consumption
	3%	4%	4%	7%
C – Manufacturing	Employees	Energy consumption	Working hours	Output value
	2%	4%	4%	8%
D – Electricity, Gas, Steam and Air Conditioning Supply	Energy production	Heat generation	Electricity generation	Fuel input
	21%	21%	21%	22%
E – Waste Management and Remediation Activities	Employees	Waste input	Output value	Working hours
	28%	32%	37%	49%

Forecasts and backcasts were performed for all trends and economic sectors including their different independent variables.

Figures 4 to 6 give a graphical example of forecast and backcast results compared to estimation results when including all observations, using the local linear trend and several independent variables relating to economic sector B. Shading in light blue marks the time interval for which forecasts and backcasts were performed.

Figure 4:
Estimation results for the total water input of economic sector B for the local linear trend and four different independent variables
in mil. m³

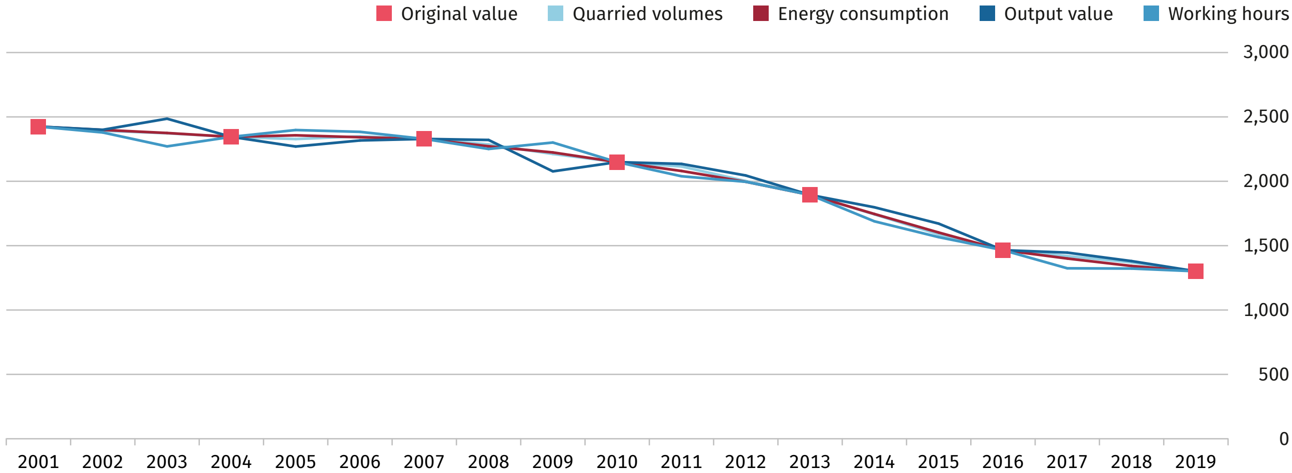


Figure 5:
Forecast results for the total water input of economic sector B for the local linear trend and four different independent variables
in mil. m³

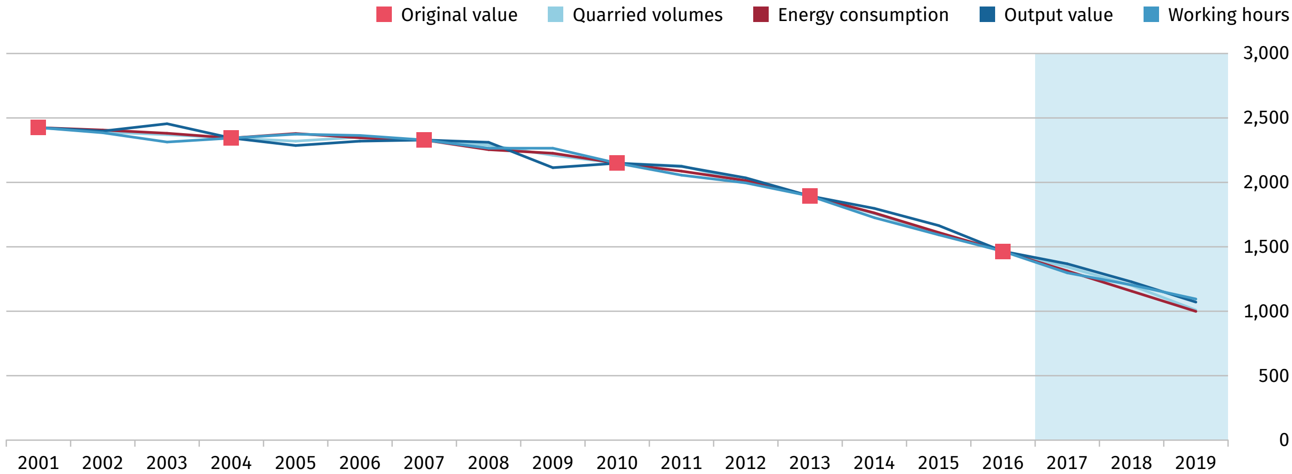
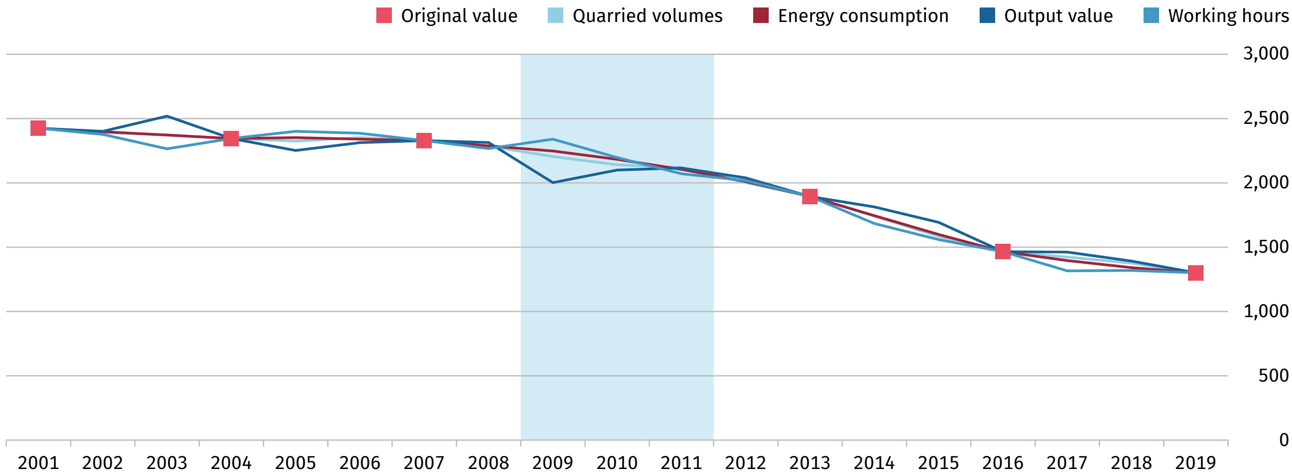


Figure 6:
Backcast results for the total water input of economic sector B for the local linear trend and four different independent variables
in mil. m³ (2010 missing)



After performing all the aforementioned calculations and evaluations for each economic sector, we eventually decided to use the independent variables displayed in Table 14 in the SSM:

Table 14:
Eventually chosen independent variables for the State-space model per economic sector

Economic sector (1-digit sector level)	Independent variable
A – Agriculture, Forestry and Fishing	Yield per hectare
B – Mining and Quarrying	Quarried volumes
C – Manufacturing	Energy consumption
D – Electricity, Gas, Steam and Air Conditioning Supply	Energy production (excluding renewable energies)
E – Waste Management and Remediation Activities	Working hours
F – Construction	Construction output value
G – Wholesale and Retail Trade	Output value
H – Transporting and Storage	Number of passengers (air, railway and ship)
I – Accommodation and Food Service Activities	Overnight stays
J – Information and Communication	Working hours
K – Financial and Insurance Activities	Working hours
L – Real Estate Activities	Working hours
M – Professional, Scientific and Technical Activities	Output value
N – Administrative and Support Service Activities	Output value
P – Education	Number of pupils and students
Q – Human Health and Social Work Activities	Health expenditure
R – Arts, Entertainment and Recreation	Number of employees
S – Other Service Activities	Output value

3.2.4 Limitations

In general, the quality of regression analysis models depends heavily on the number of observations. Small data sets bear the risk of producing poor estimation results with large standard errors. A common rule of thumb is therefore that for every predictor variable (e.g. a trend component) at least ten observations should be available (Pennsylvania State University, 2018). Nevertheless, the authors' summary also states that the number of required observations depends strongly on the data, since well-fitting data also generate reliable results with lower observation numbers. Since we only have four to seven observations per economic sector, special attention should be paid to this issue of small data sets and low numbers of observations when establishing and evaluating different models.

We therefore decided to only work with a single independent variable per economic sector. Tests with two or three independent variables often showed quite delusive results (extremely high or low values in selected years). The same principle of simplicity was also considered when evaluating the different trend options. We soon came to the decision that trends with auto-regressive components, like the damped local linear trend or ARIMA trend, while possibly reflecting more closely the time series character of our data, could simply lead to an over-parameterisation of the model.

Added to this consideration, Bollineni-Balabay et al. (2016) emphasise the fact that structural time series models like the SSM possess the advantage of "[…] borrowing strength over time", since the entire set of observations is included in the modelling calculations. This justifies our selection of the SSM in favour of other regression models, especially in light of our limited number of observations.

Table 15 provides an extract of the SAS output for economic sector B – Mining and Quarrying and economic sector I – Accommodation and Food Service Activities, using the integrated random walk as a trend, with quarried volume and overnight stays as the respective independent variables. Estimated values in interim years, standard errors and the 95 % confidence intervals reveal differing model qualities depending on the economic sector: while standard errors are quite low for economic sectors with higher numbers of observations, economic sectors with only four observations exhibit greater uncertainties, expressed in wide confidence intervals and relatively higher standard errors.

This result suggests two positive factors. First, for the economic sectors with the greatest total water inputs in the annual estimation (B, C, D), seven observations are available. Moreover, it can be assumed that the estimation quality of the other economic sectors will increase in future when additional water statistics data are released and our calculations can be updated.

Table 15:
Annual estimation results, standard errors and confidence intervals for total water input (mil. m^3) in economic sectors B and I

Interim year	Estimation	Standard error	95 % confidence intervall	
			Upper limit	*Lower limit*
Economic sector B – Mining and Quarrying				
2002	2,392	4.589	2,383	2,401
2003	2,373	4.661	2,364	2,382
2005	2,326	5.672	2,315	2,337
2006	2,350	4.851	2,341	2,360
2008	2,287	4.550	2,278	2,296
2009	2,211	4.977	2,202	2,221
2011	2,121	8.794	2,103	2,138
2012	2,004	5.019	1,994	2,014
2014	1,741	4.507	1,732	1,750
2015	1,586	5.390	1,576	1,597
2017	1,421	6.588	1,408	1,434
2018	1,372	7.542	1,357	1,387
Economic sector I – Accommodation and Food Service Activities				
2011	4.841	0.81	3.253	6.428
2012	8.093	1.367	5.414	10.772
2014	12.158	0.644	11.896	14.421
2015	14.597	0.648	13.327	15.868
2017	17.478	0.874	15.765	19.19
2018	18.853	0.619	17.64	20.066

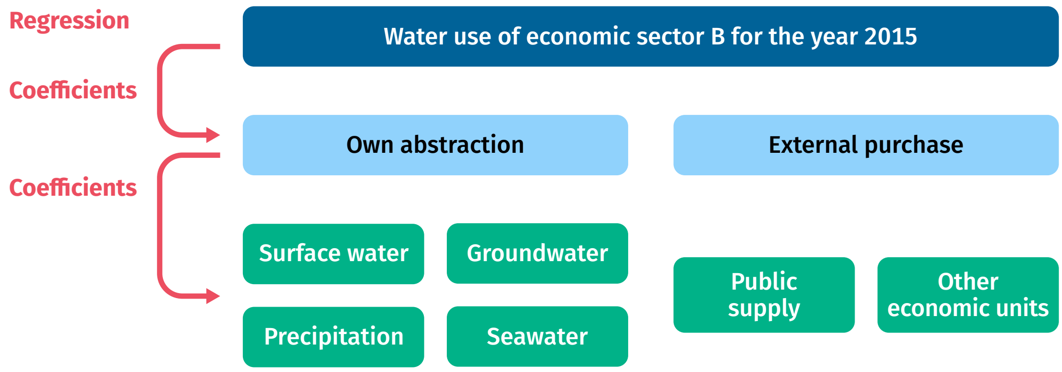
3.3 Coefficients

3.3.1 Initial situation

With the help of the State-space model implementation explained in section 3.2, a benchmark value for total water input is created for each economic sector on the 1-digit level.

In a next step, we split this benchmark into several related reporting items in the water statistics. This top-down disaggregation is achieved with the help of coefficients, calculated from the available observations. Figure 7 provides a schematic example of the further processing of the benchmark: the total water input (in this example from economic sector B) is first subdivided into ‘own abstraction’ and ‘external purchase’ of water. Secondly, the own abstraction is further divided into the different water resources and the external purchase into the purchase sources. Another example would be the division of the total water input into different water applications like ‘distribution to other units’, ‘cooling water’, ‘irrigation water’ etc.

Figure 7:
Example of the subdivision of the benchmark value for total water input: practical implementation



As already touched upon, the calculation of the coefficients is based on the annual values for those years where water statistics data are available. In detail, for each of these years and for each economic sector, the value for the corresponding water items was divided by e.g. the total water input. To continue with the example in Figure 4, the coefficients for own abstraction and surface water of economic sector B in the year 2016 were obtained according to the calculation presented in example calculation 9.

Example calculation 9:
Calculation of coefficients of some water items provided in the water statistics

Relevant data for economic sector B, year 2019:

- Total own abstraction: 1,447,943 m^3
- Total purchase of water: 17,081 m^3
- Abstraction of surface water: 293,242 m^3

Calculation steps:

1,447,943 m^3 + 17,081 m^3 = 1,465,024 m^3	Total water input
1,447,943 m^3 / 1,465,024 m^3= 0.988	Coefficient for own abstraction
293,242 m^3 / 1,447,943 m^3 = 0.203	Coefficient for abstraction of surface water

In a next step, the time series comprising the coefficients for the available years is complemented by a straightforward linear interpolation to obtain values for the interim years. This interpolation is once more conducted in SAS with the procedure ‘Proc EXPAND’ and using the ‘method=joint’ option to prevent negative values for the coefficients. These coefficients are then applied to the total water input estimated by SSM, following the previously mentioned ‘top-down’ principle. The final results are annual water tables, containing the same water items as the available water statistics publications. Note that this applies to all economic sectors on the 1-digit level, excluding the economic sectors E 36 (public water supply) and E 37 (public wastewater disposal). Calculation of these is based on the ‘indirect calculations’ approach set out in section 3.5.

3.3.2 Limitations

Although this approach seems relatively intuitive, a few limitations should be mentioned. It is necessary to ensure that the coefficients calculated for interim years retain their coherence within water item groups. For example, the sum of the single water resource coefficients (surface water, groundwater, seawater, precipitation) has to add up to 1 because the higher-level position ‘own water abstraction’ consists precisely of these four types of resource.

In general, this approach is unable to reflect possible non-linear changes within the different water items in the interim years between two observation years. It is for example possible that the own water abstraction of economic sector B in 2015 differs more strongly from the previous year than the implemented linear interpolation between 2013 and 2016 would suggest.

Nevertheless, we judge this approach to be quite credible, because the coefficients mostly do not show major variances within the observation time series available from water statistics. We assume that conducting additional regression analyses on each water item would involve much greater uncertainties than performing subdivision according to the 'top-down' principle.

3.4 Direct calculations

3.4.1 Initial situation

Direct calculations are the most straightforward and preferred solution to the annual estimation problem. This approach is based on the principle that some water items can be estimated without recourse to the water statistics, since the data basis for the calculations can be accessed in its entirety from other sources.

3.4.2 Practical implementation

Regarding the annual estimation of German water accounts, this approach applies to the following reporting items:

- Soil water abstraction
- Irrigation water of economic sector A 01
- Water volumes in livestock farming (drinking and cleaning water)
- Water incorporated in exports and imports
- Water export and import of tourists and students
- Water requirement and use of economic sector O

All of these calculations can be consulted in the corresponding sections of chapter 2.

3.4.3 Limitations

This approach is only limited by the fact that the data sources for the individual calculation methods have to be available with annual periodicity.

3.5 Indirect calculations

3.5.1 Initial situation

As a fourth and last approach to finalise the annual estimation, we implemented the notion of indirect calculations. These comprise water items in the PSUT that can be derived from already calculated values.

Obviously, this comprises mainly the 'total' positions in the PSUT, e.g. the rows and columns named 'total supply' or 'total use'. Nevertheless, the public water supply (E 36) and public wastewater disposal (E 37) were also excluded from the estimation approaches in the previous sections, because their water volumes are mainly based on the demands and requirements of economic sectors and private households. The latter also represent a special case and are explained in more detail in the following section.

It should also be noted that indirect calculations may include steps from other approaches like the coefficients or direct calculations, but in principle they reference data that has been calculated before.

3.5.2 Practical implementation

Private households

The water consumption of private households in the interim years is calculated with the help of data provided in the WSP. In this case the water delivery from public water supply to private households (including small industries!) is recorded in litres per day and per inhabitant. For the interim years this delivery is, like the coefficients, interpolated with Proc EXPAND and subsequently multiplied by the total number of inhabitants, available in the official German population statistics. To obtain the final external public water purchase of private households, the share of small industries (9 %) needs to be deducted. This external public purchase is once again used as a benchmark to derive other water items, e.g. the non-connected residents' own abstraction activities.

Similar calculations are conducted for wastewater, where the daily wastewater volume per inhabitant (also available in the WSP and interpolated with Proc EXPAND) is used to derive the total wastewater of private households received by public wastewater management.

Other calculations like the additional purchase of precipitation and groundwater are calculated according to the procedure presented in section 2.5.

Economic sector E 36

To calculate the water items of public water supply, the sum of public water received from the economic sectors and from private households represents the predominant quantity. Additional items are derived once again with the help of coefficients, always based on the sum of public water purchase by economy and private households. These additional items are

- Own water requirement
- Water losses
- Distribution to other countries
- Own water abstraction (including the different water resources)
- External water purchase

Economic sector E 37

The same approach was applied to public wastewater disposal, where the basic volumes consist of wastewater discharged into the public sewer system by the economic sectors and by private households. Subsequently, the other relevant water items such as precipitation water are derived with the help of coefficients.

3.5.3 Limitations

This approach has the limitation that especially E 36 and E 37 depend exclusively on the rest of the economy and on private households. There is no possibility to account for potentially rising or declining water requirements for own use during interim years.

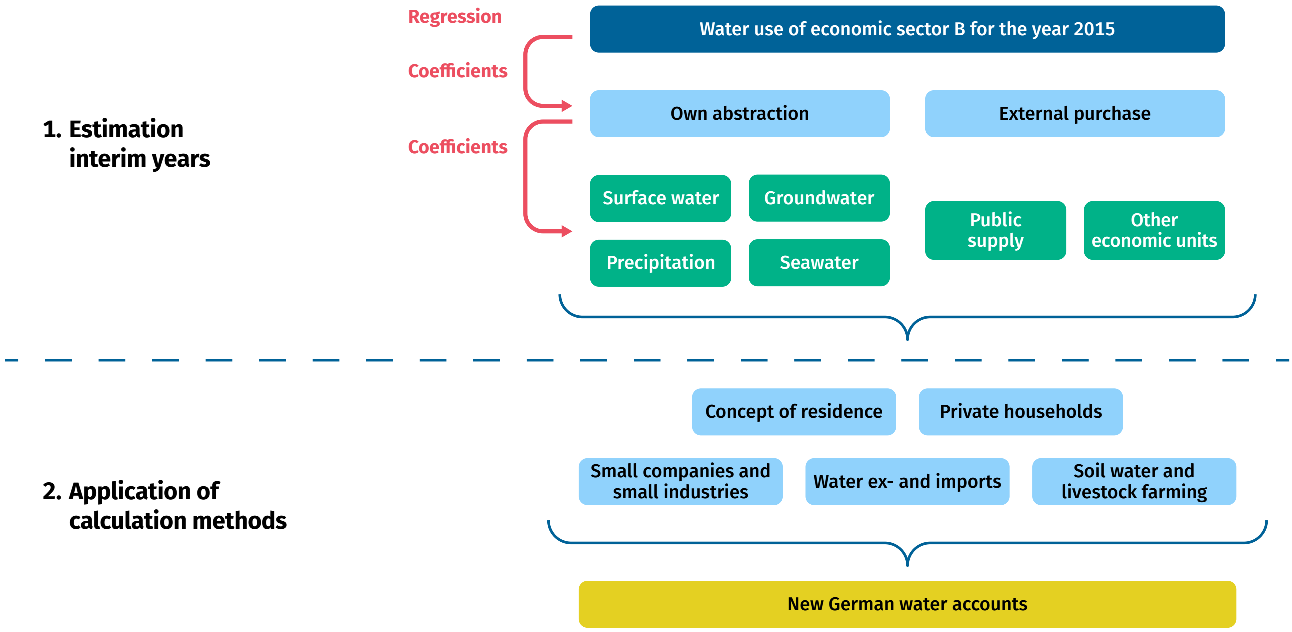
Regarding E 37, one improvement would be to relate the collected precipitation volumes to the actual annual precipitation. Chapter 5 outlines one possible calculation approach for this.

The same applies to private households where annual variations in water requirement and therefore in external purchase or own abstraction cannot be displayed by the current approach. Similar to the case of E 37, the inclusion of precipitation amounts or (summer) temperature readings could improve the estimation.

3.6 Conclusions of the annual estimation

The aim of the annual estimation was to provide reasonable estimates for the years not covered by water statistics, at least on the level of detail (regarding economic sectors and water items) required to fill in the PSUT of the SEEA-CF. This breakdown into economic sectors was our major challenge since we wanted to display the different water requirements as accurately as possible. After evaluating several regression-based models, we finally chose to implement a State-space model with a trend component and an economic sector-specific independent variable, calculating a benchmark for the total water input even down to the 1-digit level (letters A to S). This benchmark forms the basis for a further breakdown in the items covered by the German water statistics every third year, providing the opportunity to rely on the same calculations presented in chapter 2 for the observation years as well as for interim years, ensuring greater consistency within the new time series. This two-stage procedure of the annual estimation (shown in Figure 8), was complemented by additional direct and indirect calculation of water items from different economic sectors or from private households.

Figure 8:
Outline of the two-stage procedure of data generation for interim years



Previous sections have outlined the problems and limitations of this calculation approach, especially in terms of the low number of observations, which restricts the quality of the models and the results.

Nevertheless, we believe our implementation of the SSM was considered with care and is supported by a range of evaluation methods. Furthermore, annual data provide an ideal opportunity for diverse applications. For example, several indicators for the United Nations' Sustainable Development Goals (SDGs) rely on various water items. Annual data are also advantageous regarding potential future legal obligations to report country-specific water accounts to the European Union. Overall, publication of annual results, accompanied by specific information on how these data were generated and what precise categories they cover, seems to us to be a fully justified measure.

A huge advantage of the State-space model lies in its flexibility and adaptability. Because our calculations are based on the data provided by the German water statistics authorities, every three years new observations will be available to update and hopefully improve the accuracy of the estimation results. In particular, the upcoming publications will be crucial, because only then will we see if the SSM is able to reflect possibly considerable changes in the water requirements of the economy as a whole. For example, due to the economic slowdown exacerbated by the recent Covid-19 restrictions implemented in 2020 and the closing of many businesses in the interim years 2020 and 2021.

4 Results

This chapter presents and briefly discusses some of the main results of the new German water statistics.

Table 16 and Table 17 show the separate supply and use tables according to the SEEA-CF. We made some small adjustments to align the reporting items more closely with our available data. For example, row (II) 'Abstracted water' in the use table was altered by excluding the items 'Hydroelectric power generation' and 'Mining'. Instead we added 'Production water', comprising water volumes like soil water abstracted by cultivated plants, or the entire water usage of private households except for irrigation water. Regarding the supply table, we added two rows in (IV) 'Return flows of water' to include more detailed information about whether wastewater returned to the environment has been treated or not.

Table 16:
SEEA-CF supply table for Germany in 2019 in mil. m³

SEEA-CF Supply Table	Industries (by ISIC category)							Households	Rest of the world	Flows from the environment	Total supply
	1-3	5-9	10-33	35	36	37	38-99		Imports		
(I) Sources of abstracted water											
Inland water resources											
Surface water										15,329	**15,329**
Groundwater										7,536	**7,536**
Soil water										45,268	**45,268**
Total										68,133	**68,133**
Other water sources											
Precipitation										2,757	**2,757**
Sea water										171	**171**
Total										2,928	**2,928**
Total supply abstracted water										71,060	**71,060**
(II) Abstracted water											
For distribution	48	186	150	421	4,731		207		104		**5,847**
For own use	46,295	239	3,794	8,330	624	0	387	634			**60,303**
(III) Wastewater and reused water											
Wastewater											
Wastewater to treatment	3	10	545	95	-		524	3,957			**5,133**
Own treatment	0	221	3,528	8,463	0	3,915	469	82			**16,678**
Reused water produced											
For distribution											
For own use											
Total	3	231	4,073	8,558	0	3,915	993	4,039			**21,812**
(IV) Return flows of water											
To inland water resources											
Surface water	79	227	3,551	8,465	-	9,048	479	49			**21,898**
Groundwater					493			33			**526**
Soil water	187	0	0	0	-	-	3	6			**196**
Total	266	227	3,551	8,465	493	9,048	482	88			**22,620**
To other sources											**0**
Total return flows	266	227	3,551	8,465	493	9,048	482	88			**22,620**
of which: treated wastewater	-	27	604	103	-	6,967	123	82			**7,906**
of which: untreated wastewater	-	194	2,924	8,360	-	2,081	346	-			**13,906**
of which: Losses in distribution[1]					473						**473**
(V) Water consumption											
Evaporation of abstracted water	134	9	252	351	-	-	53	-			**798**
Transpiration	45,740	0	5	2	-	-	54	137			**45,939**
Water incorporated into products	158	16	184	11	-	-	24	2	58		**453**
Total supply	**92,643**	**908**	**12,009**	**26,139**	**5,848**	**12,963**	**2,200**	**4,900**	**162**	**71,060**	**228,832**

[1] Only including losses in distribution of the public water supply (E 36)

Table 17:
SEEA-CF use table for Germany in 2019 in mil. m³

SEEA-CF Use Table	Industries (by ISIC category)							Households	Accumulation	Rest of the world	Flows from the environment	Total supply
	1-3	5-9	10-33	35	36	37	38-99			Exports		
(I) Sources of abstracted water												
Inland water resources												
Surface water	323	243	3,333	8,587	1,576	781	486					**15,329**
Groundwater	742	1,038	707	64	3,779	781	144	281				**7,536**
Soil water	45,268											**45,268**
Total	46,333	1,280	4,040	8,651	5,355	1,562	630	281				**68,133**
Other water sources												
Precipitation	10	8	27	1	-	2,353	5	353				**2,757**
Sea water	0	0	2	168	-	-	1					**171**
Total	10	9	29	168	0	2,353	6	353				**2,928**
Total supply abstracted water	46,342	1,289	4,069	8,819	5,355	3,915	636	634				**71,060**
(II) Abstracted water												
Distributed water	63	15	1,772	364	33	-	632	3,550	74	30		**6,534**
Own use	46,295	239	3,794	8,330	624	0	387	634				**60,303**
Total	46,358	254	5,566	8,694	657	0	1,019	4,184				**66,733**
of which:												
Cooling water	-	10	4,318	8,544	-	-	471					**13,343**
Production water	45,735	228	1,004	134	154	-	336	4,026				**51,615**
Irrigation water	623	0	5	2	-	-	58	116				**806**
Staff-used water	-	1	55	2	-	-	130					**187**
(III) Wastewater and reused water												
Wastewater												
Wastewater received from other units						5,133				-		**5,133**
Own treatment	0	221	3,528	8,463	0	3,915	469	82				**16,678**
Reused water produced												
Distributed reuse												
Own use												
Total	0	221	3,528	8,463	0	9,048	469	82		0		**21,812**
(IV) Return flows of water												
Returns of water to the environment												
To inland water resources											22,620	**22,620**
To other sources											0	**0**
Total return flows											22,620	**22,620**
(V) Water consumption												
Evaporation of abstracted water											798	**798**
Transpiration											45,939	**45,939**
Water incorporated into products									409	44		**453**
Total use	**92,700**	**1,764**	**13,164**	**25,976**	**6,013**	**12,963**	**2,125**	**4,900**	**409**	**44**	**69,358**	**229,415**

We also deviated from the SEEA-CF concept regarding the classification of private households' water volumes: according to the SEEA-CF definition, private households' own abstraction of water should be recorded as volumes belonging to the public water supply (E 36). Our tables display the own abstractions (groundwater and precipitation) in the household column, since we believe that this enhances our table's informational value for users.

Regarding the basic requirement of the PSUT, namely that use and supply have to be equal, our results slightly deviate from this condition. The core problem appears to be that abstracted water for distribution (supply) and distributed water which is received do not match perfectly. In fact, our figures suggest that there is more water received from distribution than is supplied by distribution. Very likely this is because of inconsistencies within the WSNP, because differences in water volumes regarding the exchange between public water supply and the rest of the economy are accounted for in the small economies' calculation. This circumstance also creates discrepancies within the different economic sectors (columns). For example, economic sector '38-99' shows a total supply of 2,200 mil. m³, compared to a total use of only 1,125 mil. m³.

Zooming further in on the data, the figure for soil water is particularly striking, because its share of the total use of water was about 64 % in 2019. This is illustrated in Figure 9 where soil water is included in the 'production water' category for the economic sector 'Agriculture, forestry and fishing'. Because soil water use only occurs in agriculture, the relation of the economic sector A compared to the other economic sectors and to private households is very similar. It is important to classify soil water values properly because, in contrast to other abstracted volumes, soil water is mostly re-released into the environment instantaneously by transpiration. Another characteristic of soil water lies in the fact that its abstraction by plants is, beside the deep percolation into the groundwater in saturated soils, the only possibility for people to use this water for economic purposes.

Figure 9:
Water use according to different areas of application and economic sectors for the year 2019.
in mil. m³ – Soil water as part of the production water is included

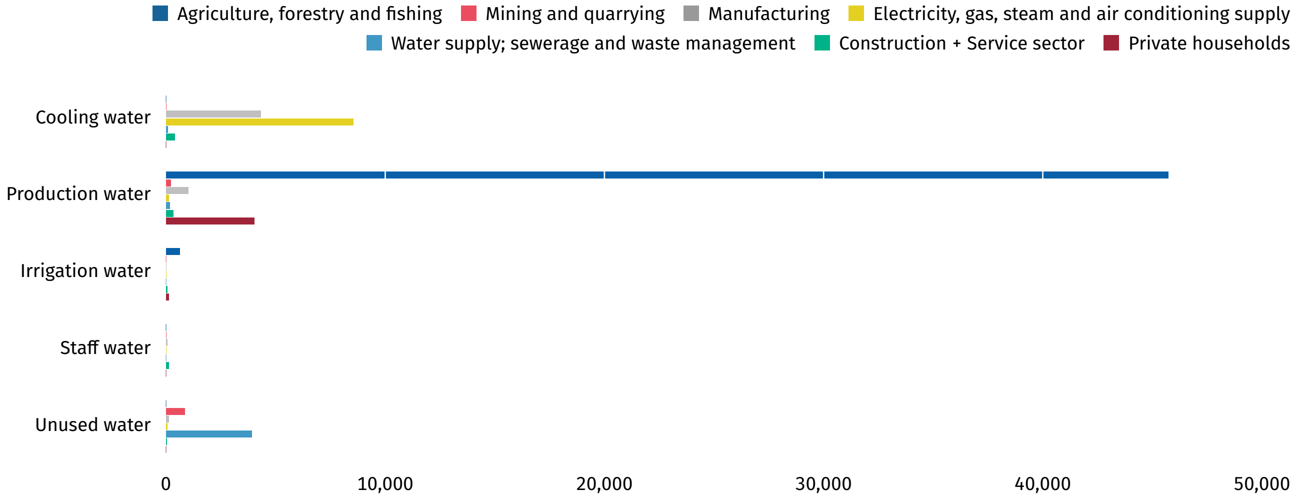


Figure 10:
Water use according to different areas of application and economic sectors for the year 2019.
in mil. m³ – Soil water as part of the production water is excluded

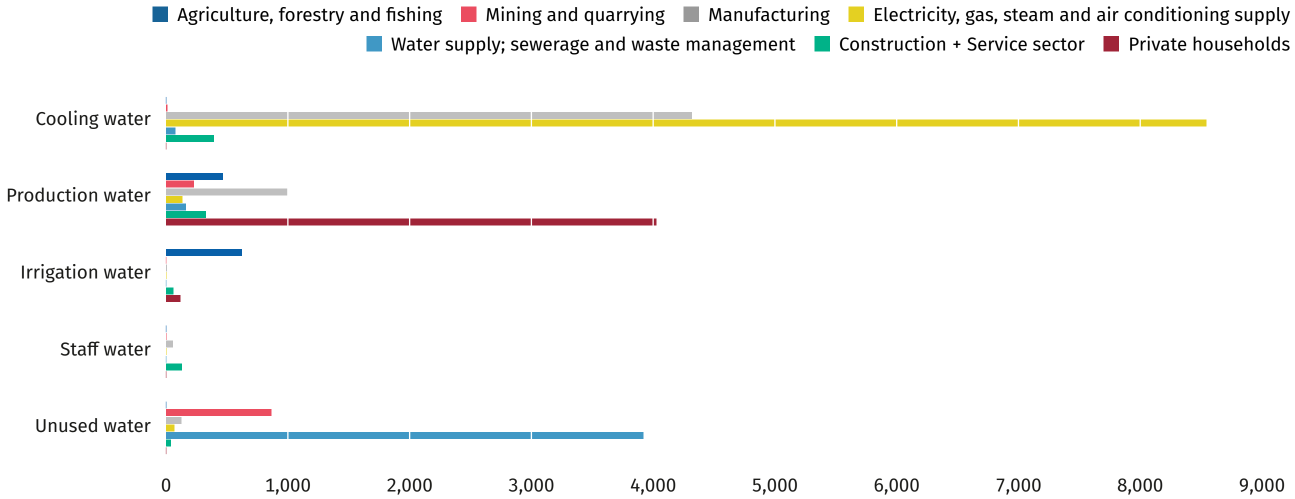


Figure 10 again shows the areas of application for the different economic sectors but this time without soil water, indicating that especially the category ‘Electricity, gas, steam and air conditioning supply’ also possesses high water requirements. The cooling water from these suppliers is subsequently returned to the environment, mainly in the form of untreated wastewater.

Water asset accounts for the years 2015 to 2019 are displayed in Table 18. Only the rows ‘Returns’ and ‘Abstraction’ are directly filled with values from the new water accounts. In detail, ‘Returns’ equals the total supply position ‘Total return to inland water resources’ and ‘Abstraction’ equates to the total use position ‘Total use abstracted water’. Additionally, the transpiration volumes of soil water through agriculturally cultivated plants have to be subtracted from ‘Evaporation and actual evapotranspiration’, because these volumes are already recorded in the ‘Abstraction’ row. The other positions are filled with annual data provided by the ‘Federal Institute of Hydrology’ (BfG).

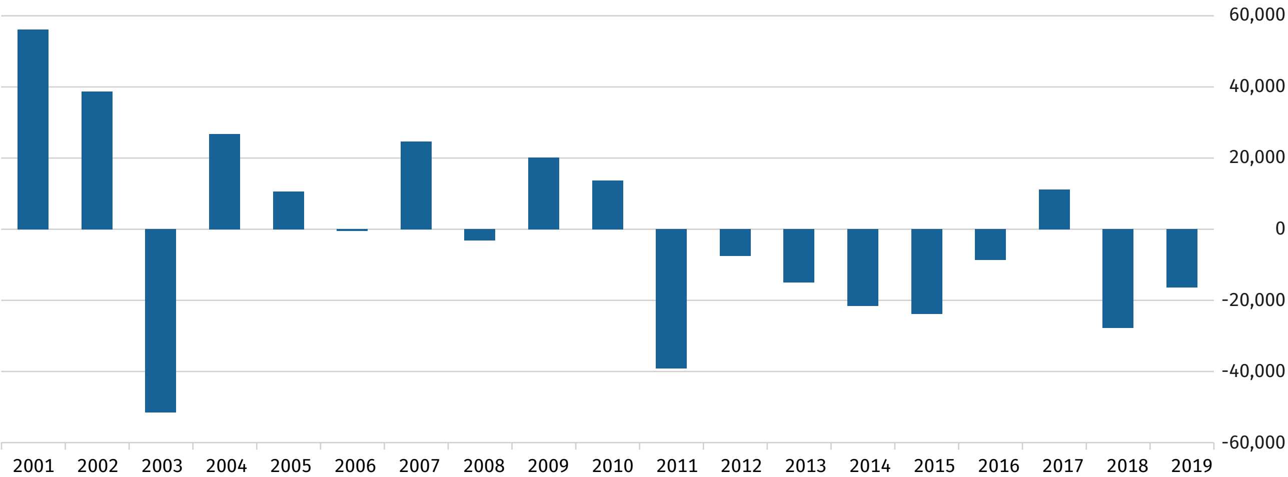
Table 18:
Eurostat asset accounts table for Germany, 2015-2019, in mil. m³

Reporting item	2015	2016	2017	2018	2019
Additions to stock – total	362,093	384,403	420,568	313,574	378,120
Returns	27,693	27,203	24,968	23,874	22,620
Precipitation	274,100	286,700	336,300	230,600	289,100
Inflows from other territories	60,300	70,500	59,300	59,100	66,400
Reductions in stock – total	385,855	392,987	409,431	341,314	394,560
Abstraction	77,878	77,584	77,304	66,728	71,060
Evaporation and actual evapotranspiration	163,077	155,103	183,027	134,386	183,100
Outflows to other territories	103,000	119,800	101,300	102,200	102,400
Outflows to the sea	41,900	40,500	47,800	38,000	38,000
Balance: additions – reductions	-23,762	-8,584	11,137	-27,740	-16,440

[1] Includes the return to inland water resources (Surface water, groundwater, soil water).
[2] Without transpiration of soil water by agriculturally cultivated plants, since their volumes are already recorded in the 'Abstraction' position in form of soil water.

The time series illustrates that returns and abstraction are declining, whereas the remaining positions vary to differing degrees throughout the years. Especially when including the whole time series as of 2001 (see Figure 11), there seems to be a current trend of an increased incidence of negative balances compared to past years: between 2010 and 2019, only two years show higher additions than reductions, leading to a positive water balance. Taking the average between 2001 and 2019 reveals a negative average balance of -960 mil. m³ per year.

Figure 11:
Time series of the German water balance according to the SEEA-CF asset accounts table, 2001-2019
in mil. m³



For our national publication we devised an additional data structure, deviating from the PSUT concept. In detail, we merged the supply and use tables to create one summary table. The result, including data for 2017 to 2019, is presented in Table 19. The ‘Statistical difference’ rows are necessary to account for inconsistencies in the distribution of water and the missing data for the service sector up to 2010. We have also included additional information on exports and imports, differentiating between water exchanges of the public water supply (E 36), water incorporated in trading goods and water consumption of tourists and students.

Table 19:
Combined supply and use table for the national publication of German water accounts, 2017-2019, in mil. m³

Water item[1]	2017	2018	2019
Water abstraction from the environment	77,304	66,728	71,060
Abstraction from inland water resources	73,764	63,501	68,133
Surface water	16,625	15,998	15,329
Groundwater	7,583	7,696	7,536
Soil water[2]	49,556	39,806	45,268
Abstraction from other water resources	3,540	3,227	2,928
Precipitation	2,888	2,834	2,757
Sea water	653	393	171
Distribution of water within the economy			
Water distribution	5,628	5,690	5,743
External water purchase	6,231	6,362	6,430
Statistical difference[3]	-603	-671	-687
Water imports from foreign economies	154	170	162
External water purchase	2	2	2
Water consumption of national residents in foreign countries	93	109	102
Incorporation of water in imported products	60	59	58
Water utilisation	77,215	66,684	70,966
Cooling water	15,015	14,171	13,343
Production water	55,784	46,104	51,615
Of which: incorporation of water in products	357	348	385
Irrigation water	683	901	806
Of which: incorporation of water in plants	12	10	12
Staff water	187	188	187
Unused water	5,546	5,320	5,014
Distribution and treatment of wastewater within the economy			
Distribution of wastewater			
Distribution of wastewater	5,121	5,160	5,133
External wastewater purchase[4]	5,121	5,160	5,133
Statistical difference[5]	-	-	-
Treatment of wastewater			
Treated wastewater	8,288	8,148	7,906
Untreated wastewater	15,794	14,853	13,906
Water exports foreign economies	69	71	74
Water distribution	10	11	11
Water consumption of foreign residents on national territory	17	18	19
Incorporation of water in exported products	41	42	44

Water item[1]	2017	2018	2019
Return of water to the environment	76,371	65,740	69,831
Return to inland water resources	24,968	23,874	22,620
Surface water	24,157	23,095	21,898
Groundwater	621	572	526
Soil water	191	206	196
Return to the atmosphere	50,946	41,403	46,738
Evaporation	818	833	798
Transpiration	50,128	40,570	45,939
Other returns	457	463	473
Losses in distribution[6]	457	463	473

1 Reference years 2001 up to 2009 only cover economic sectors A to D, as well as E36 and E37 (without economic sectors E38 and E39 and F to T).
2 Includes the abstraction of soil water by agriculturally cultivated plants (economic sector A01)
3 Results from inconsistencies within the water statistics survey and the circumstance that data for economic sectors E38 and E39 and F to T is lacking up to 2010.
4 Includes solely the external purchase of wastewater by the public wastewater disposal companies (economic sector E37).
5 Results from lacking data for economic sectors E38 and E39 and F to T up to 2010.
6 Includes solely losses in distribution by the public water suppliers (economic sector E36).

In the national publication we also provide selected reporting items in separate tables as a time series with NACE breakdown, where our level of detail exceeds the one proposed in the PSUT (partially on a 2- to 3-digit level, especially for economic sectors A to H). An example for the total water abstraction from the environment is provided in Table 20.

Table 20:
Total abstraction of water from the environment per economic sector according to the national publication of the German water accounts, 2017-2019, in mil. m³

WZ2008	Economic sector	2017	2018	2019
A	Agriculture, forestry and fishing	50,477	40,964	46,342
01	Crop and animal production, hunting and related service activities	.	.	46,274
02	Forestry and logging	.	.	1
03	Fishing and aquaculture	.	.	67
B	Mining and quarrying	1,406	1,358	1,289
05	Mining of coal and lignite	.	.	1,014
06	Extraction of crude petroleum and natural gas	.	.	1
07-09	Mining of metal ores, mining support service activities	.	.	274
C	Manufacturing	4,273	4,136	4,069
10-12	Manufacture of food products, beverages and tobacco products	.	.	290
13-15	Manufacture of textiles, wearing appeal, leather and related products	.	.	12
16	Manufacture of wood and of products of wood and cork (except furniture)	.	.	4
17	Manufacture of paper and paper products	.	.	388
18	Printing and reproduction of recorded media	.	.	3
19	Manufacture of coke and refined petroleum products	.	.	158
19.1	Manufacture of coke oven products	.	.	-
19.2	Manufacture of refined petroleum products	.	.	158
20	Manufacture of chemicals and chemical products	.	.	2,243
21	Manufacture of basic pharmaceutical products and preparations	.	.	45
22	Manufacture of rubber and plastic products	.	.	51
23	Manufacture of other non-metallic mineral products	.	.	138
23.1	Manufacture of glass and glass products	.	.	6
23.2-9	Manufacture of ceramics, Processing of non-metallic mineral products	.	.	132
24	Manufacture of basic metals	.	.	518
24.1-3	Manufacture of basic iron and steel and of ferro-alloys	.	.	413
24.4	Manufacture of basic precious and other non-ferrous metals	.	.	95
24.5	Casting of metals	.	.	11
25	Manufacture of fabricated metal products, except machinery and equipment	.	.	17
26	Manufacture of computer, electronic and optical products	.	.	35
27	Manufacture of electrical equipment	.	.	8
28	Manufacture of machinery and equipment n.e.c.	.	.	33
29	Manufacture of motor vehicles, trailers and semi-trailers	.	.	95
30	Manufacture of other transport equipment	.	.	11
31-32	Manufacture of furniture and other manufacturing	.	.	3
33	Repair and installation of machinery and equipment	.	.	15
D	Electricity, gas, steam and air conditioning supply	10,629	9,730	8,819
35.1/.3	Electric power generation, steam and air conditioning supply	.	.	8,789
35.2	Manufacture of gas	.	.	30
E	Water supply, sewerage and waste disposal	9,619	9,544	9,442
36	Water collection, treatment and supply	5,186	5,241	5,355
37-39	Sewerage, waste collection and remediation activities	.	.	4,087
37	Sewerage	4,359	4,163	3,915
38-39	Waste collection and remediation activities	.	.	172

WZ2008	Economic sector	2017	2018	2019
F	Construction	9	8	7
41-42	Building construction and civil engineering	.	.	2
43	Specialised construction activities	.	.	5
G	Wholesale and retail trade; Repair of motor vehicles and motorcycles	11	12	11
45	Wholesale and retail trade and repair of motor vehicles and motorcycles	.	.	5
46	Wholesale trade, except of motor vehicles and motorcycles	.	.	5
47	Retail trade, except of motor vehicles and motorcycles	.	.	1
H	Transportation and storage	6	6	6
49.1-2	Passenger (interurban) and freight rail transport	.	.	-
49.3-5	Other land transport; transport via pipelines	.	.	0
50	Water transport	.	.	-
51	Air transport	.	.	0
52	Warehousing and support activities for transportation	.	.	6
53	Postal and courier activities	.	.	0
I	Accommodation and food service activities	4	4	5
J	Information and communication	4	4	4
K	Financial and insurance activities	2	1	0
L	Real estate activities	84	108	117
M	Professional, scientific and auditing activities; tax consultancy	52	74	89
N	Administrative and support service activities	35	104	176
O	Public administration and defence; compulsory social security	-	-	-
P	Education	2	2	2
Q	Human health and social work activities	10	10	9
R-T	Other services	34	35	38
	All economic sectors	76,657	66,101	70,426
	+ Private households	647	627	634
	= Total abstraction of water from the environment	77 304	66,728	71,060

Deviations from the reported totals are due to rounding.

5 Potential for optimisation

Despite the extensive restructuring of these figures, it is inevitable that some topics still offer potential for further optimisation.

One important step would be to balance the total supply and the total use of the SEEA-CF PSUT. As already mentioned, we assume that the imbalance of external purchase of water and distribution of water to others is the crux of this problem. Depending on whether distribution exceeds purchase or the other way around, either the purchase of the economy has to be increased or the abstraction and distribution needs to be adapted. In terms of the latter option, one consideration could be to allow small companies to carry out their own abstractions with subsequent distribution of water.

Another enhancement could be to integrate weather and seasonal influences more comprehensively. This could apply to private households, where the water requirement for interim years (in litres per day and per inhabitant) could be calculated with a regression on temperature instead of applying a straightforward linear interpolation. A temperature coefficient would presumably also improve the estimation of drinking water volumes required by livestock farming. Lastly, precipitation collection of the public wastewater disposal in interim years could also be based on a regression performed on the annual precipitation amounts.

Regarding private households, the current calculation does not account for evaporation losses by e.g. cleaning, washing or cooking activities. Since a preliminary review of the literature did not reveal any promising data, more detailed research would be necessary to account for this phenomenon.

Finally, the soil water calculations have also not yet been fully developed and optimised. We have not accounted for the fact that yields are higher on irrigated compared to on exclusively rain-fed fields. Although various studies have addressed this topic, its practical implementation is limited by exogenous influencing factors like crop variety, soil type or weather patterns, which should also be considered. When it comes to future calculations in particular, it should be examined whether the different crop-specific coefficients (transpiration, share of irrigation etc.) ought to be updated, as the current values date back to the last century. Given the fact that the abstraction of soil water is influenced by a variety of external factors, any calculations of this will be challenging and complex. To ensure the quality of the estimated values, further validation would be advantageous. One possibility would be to extend the proposed evaluation calculation with the actual evapotranspiration data of the German Weather Service to account for the entire range of cultivated crops.

6 Conclusion

The project on 'improving water accounts', being part of the Eurostat project 2020-DE_IWSWAMFA, had the following objectives:

- Redesigning the German water accounts in order to more closely align them to international and European methodological standards
- Publishing annual water accounts values instead of at three-yearly intervals
- Undertaking a newer technical implementation of German water accounts to achieve a higher degree of automation

With the help of improved and new calculation methods, we were able to expand the reporting items of German water accounts to an extent that allows us to fill out the PSUT of the SEEA-CF almost completely. Only the positions regarding reused water remain empty, since no information on this subject is available in German water statistics. In addition, we improved several existing calculations, for example regarding small companies, irrigation water and livestock farming. In the event of an introduction of a statutory delivery of Eurostat-mandated water accounts in the future, we are now confident that we will be able to fulfil most requirements satisfactorily.

Our major challenge was the implementation of an annual estimation, since the main data basis of the German water accounts – the German water statistics – is available every three years. Producing reliable estimation results was particularly complicated because the number of observed data points is low and we had set ourselves the task of including a 'trend' component as well as economic sector-specific estimations. Despite the fact that we soon realised that a regression analysis is most suitable, a great deal of painstaking research and testing was necessary before we finally opted to implement the State-space model approach. Although we had to limit the model specification to a low number of influencing factors and opportunities to assess the models' quality were limited, we feel it is safe to assume that the goodness of fit of the estimated values is sufficiently ensured to implement the estimation procedure and publish the annual estimation results in the German water accounts. As outlined in chapter 5, however, there are still some unsolved problems – and therefore room for optimising the model – but the overall result is a clear success and shows the utmost promise for future evaluations of water use and supply.

Finally, the German water accounts calculation (including the annual estimation) was successfully and completely transferred from Excel to 'Statistical Analysis Software' (SAS). With this leap we hope to be able to reduce workloads and time pressures for new data production cycles. In addition, the implementation of new data sets or adjustment of calculations is simplified. So, in future, not only will the task become quicker, it will also be simpler to perform.

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