PRIVATE CIRCULATION
SES/1/5/1_15_0010
For comment/vote - Action Due Date: 2015/07/13

ISO/TC 207/SC 5/WG 8
Water footprint

Email of secretary:
Convenorship: SNV (Switzerland)

WD4 ISO TR 14073 Illustrative examples on how to apply ISO 14046

Document type:	Working draft
Date of document:	2015-06-15
Expected action:	COMM
Action due date:	2015-08-02
Background:	Please comment using the ISO electronic ballot portal.
Committee URL:	http://isotc.iso.org/livelink/livelink/open/tc207sc5wg8

ISO/TC 207/SC 5/WG 8 'Water footprint' **N 115**

Working Draft 4

WD4/IS0 TR 14073
Environmental management – Water footprint – Illustrative examples on how to apply ISO 14046

Dear members of WG 8

please find enclosed the WD4 of TR 14073.

You are invited to hand in

a. General comments
b. Technical comments

We are aware that there is a lot of formatting and finetuning on the document to be done. This will be done after the meeting in Dehli, when the technical content is finished.

Therefore please don't hand in comments on

a. formatting
b. numbering (of tables, figures etc.)
c. references (to tables, figures etc.)

Please comment by 2015-08-02 using the ISO electronic ballot portal.

a. See N116 'How to add your comment to a Working Group Consultation'.
b. Use the ISO commenting template in N117 and the user guide in N118 for doing so.
c. Columen 2 and 3 are used for the automated sorting of the comments, therefore
   - Please fill out column two 'Line number" for all comments exept general comments. Please give only the first line number. Don't give a range.
   - In the case of figures or tables give the line number just above.
   - Please add only the number of the clause you want to comment in column 3, don't add text and don't give a range.
   - All additional information in column 4.

	MB/ NC[1]	Line number (e.g. 17)	Clause/ Subclause (e.g. 3.1)	Paragraph/ Figure/ Table/ (e.g. Table 1)	Type of comment[2]	
		~~117-122~~				
→		117				
			~~Clause 5~~			
→		350	5			
		600	~~clause 7, figure 4~~			
→		600	7	Figure 4		
			~~Example H~~			
→		723	8			

Please note, this is not a ballot, but an informal consultation and call for comments on the WD4. Therfore the WG does not have to answer all comments at the meeting.

Best regards

Barbara Mullis
Secretary ISO/TC 207/SC5/WG 8 'Water Footprint'
SNV – Swiss Association for Standardization

Tel direct +41 52 224 54 15
Fax direct +41 52 224 54 74
barbara.mullis@snv.ch

ISO/TC 207/SC 5 N

Date: 2015-06-12

ISO/PDTR 14073

ISO/TC 207/SC 5/WG 8

Secretariat: SNV

Environmental management — Water footprint — Illustrative examples on how to apply ISO 14046

Élément introductif — Élément central — Élément complémentaire

Document type: Technical Report
Document subtype:
Document stage: (20) Preparatory
Document language: E

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 14073 was prepared by Technical Committee ISO/TC 207, *Environmental Management*, Subcommittee SC 5, *Life cycle assessment*.

This second/third/... edition cancels and replaces the first/second/... edition (), [clause(s) / subclause(s) / table(s) / figure(s) / annex(es)] of which [has / have] been technically revised.

Introduction

Principles, requirements and guidelines for the quantification and reporting of a water footprint are given in ISO 14046. The water footprint assessment according to this International Standard can be conducted as a stand-alone assessment, where only impacts related to water are assessed, or as part of a life cycle assessment. In addition, a variety of modelling choices and approaches are possible depending on the goal and scope of the assessment. The water footprint can be reported as a single value or as a profile of impact category indicator results.

This Technical Report provides illustrative examples on the application of ISO 14046 to further enhance understanding of ISO 14046 and to facilitate its widespread application.

At the time of the publication of this TR, water footprint assessment methods are developing rapidly. Practitioners are encouraged to be aware of latest developments when undertaking water footprint studies.

Fehler! Verweisquelle konnte nicht gefunden werden.

Fehler! Verweisquelle konnte nicht gefunden werden.

1 Scope

This Technical Report provides illustrative examples of how to apply ISO 14046. They should be read as offering “a way” or “ways” rather than the “unique way” of applying the standard. These examples are only a sample of the possible cases and do not present all of the details of an entire water footprint study report.

The examples are in accordance with ISO 14046 and use the same terms and definitions.

As this Technical Report does not contain prescriptive elements, it does not preclude alternative procedures to calculate the water footprint, as long as they are in accordance with ISO 14046.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14046:2014, *Environmental management – Water footprint – Principles, requirements and guidelines*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14046 apply.

4 Abbreviated terms

Editing note: The list of abbreviated terms will be completed once the final content will have been agreed on in India as it takes a lot of time to systematically realign abbreviated terms.

AOX Adsorbable Organic Halogens

BOD Biological Oxygen Demand (BOD5 means “measured during 5 days”)

COD Chemical Oxygen Demand

CWV Critical Water Volume

LCA Life Cycle Assessment

M Mega or Million (e.g. “ML” = 1’000’000 L, “Mt” = 1’000’000 t)

Mio Mega or Million (e.g. “ML” = 1’000’000 L, “Mt” = 1’000’000 t)

PDF Potentially Disappeared Fraction of species

PAF Potentially Affected Fraction of species

TOC Total Organic Carbon

WSI	Water Stress Index
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant

Editing note: Decide whether "year" is "a" or "y" or "yr" or "year" throughout the document and align the document

Editing note: References will all be put at the end of the document in a consistent way once the final content will have been agreed on in India as it takes a lot of time to systematically realign references.

5 Selection of the type of water footprint assessment

5.1 General

The water footprint assessment conducted according to ISO 14046 can be

— a stand-alone assessment where only impacts related to water are assessed or

— a part of a life cycle assessment (LCA) where consideration is given to a comprehensive set of environmental impacts, which are not only impacts related to water.

Different forms of water footprint assessment, together with the expected results, are shown in Tableau 1.

Tableau 1 — Different forms of water footprint assessments, together with the different expected results

Type of water footprint assessment	Comprehensive?	Type of water footprint or parameter	Example
Water footprint inventory	Not applicable	Water footprint inventory	A
Stand-alone water footprint assessment	Yes, all relevant environmental impacts related to water are included	Water footprint	J, N
	No, several selected impact categories related to water	Non-comprehensive water footprint	H, I, K, M, N, O
	No, one selected impact category related to water	Water X footprint (e.g. Water scarcity footprint)	B, C, D, E, F, G, H, I, P
Water footprint assessment as part of an LCA	Yes, LCA considers all attributes or aspects of natural environment, human health and resources (see ISO 14040:2006, Clause 4.1.7)	Indicator result(s) of impact category/categories related to water, e.g. water scarcity footprint, included in life cycle impact profile	L (not a very comprehensive LCA… but the idea is here)

Editing note: To clarify in India how examples H (one or two indicators to assess water eutrophication footprint) and example I and example N should be classified.

NOTE The principles of comprehensiveness for an LCA study and for a water footprint assessment are different (see ISO 14040:2006, 4.1.7 and ISO 14046, 4.13)

5.2 Choice of the type of water footprint study

5.2.1 General

The different types of water footprint are defined in ISO14046 Sections 5.4.5 to 5.4.7. The choice of a particular type of water footprint to be assessed in a water footprint study is determined in the goal and scope definition phase.

For a comparative LCA, the water footprint should always be comprehensive (i.e., containing all relevant impact categories related to water availability (or at least scarcity) and water degradation).

In addition to the goal of the study - see ISO 14046, 5.2.1 - the choice may be influenced by consideration of an appropriate system boundary, the type(s) of water resource used and affected water resources, the associated changes in water quantity and quality and determination of relevant impact assessment categories and methodologies.

An example is presented here which shows

— how the appropriate system boundary is chosen;

— which water bodies are involved ;

— if site-specific changes in water volume and/or water quality occur or not;

— how the type of water footprint to be determined is selected from this information

Figure 1 illustrates the procedural steps in choosing the type of water footprint for a water footprint study.

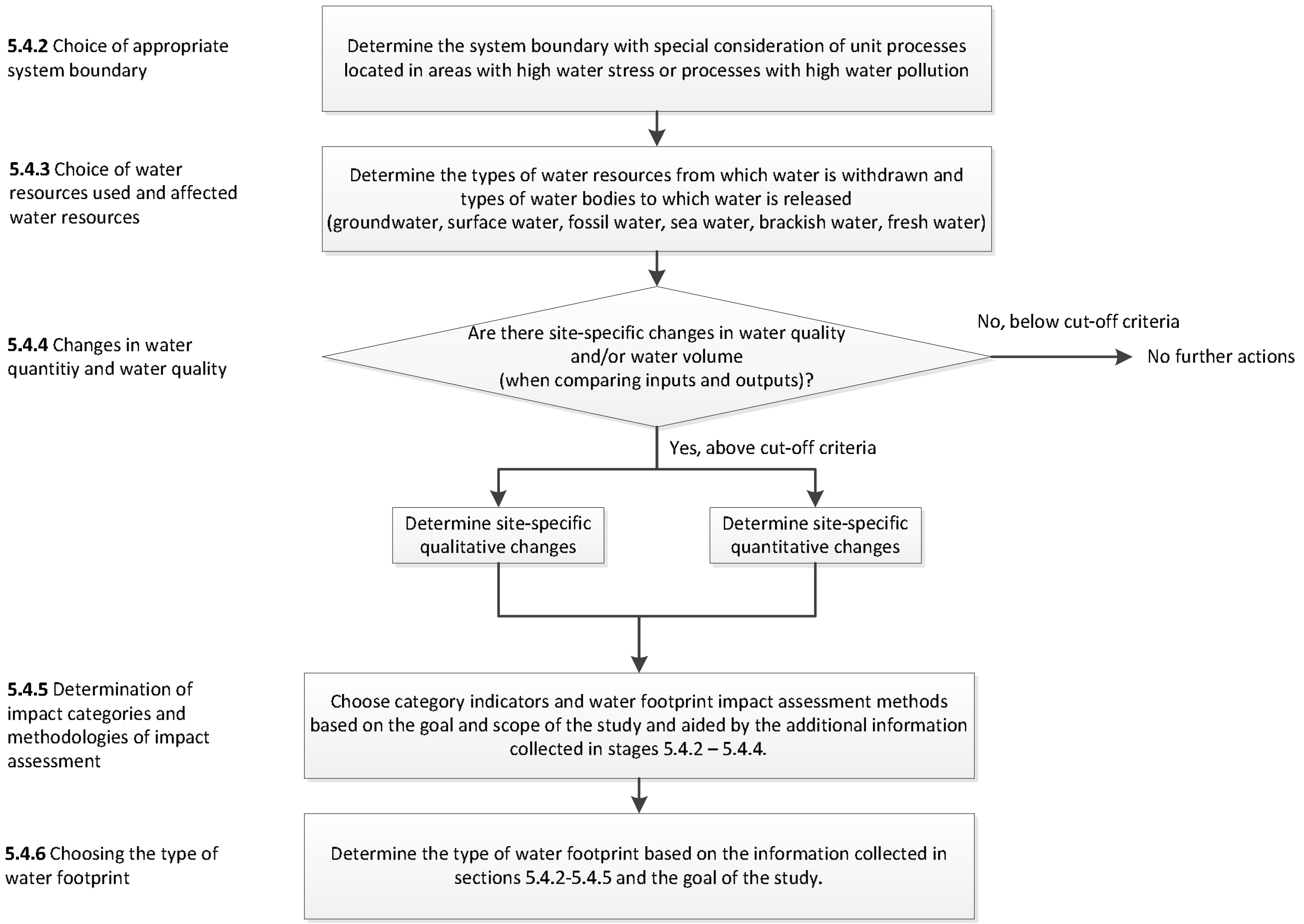


Figure 1 — Choice of the type of a water footprint assessment (example for a unit process)

Editing note: Obtain editable version of this figure → Who has the editable version of this figure?

Editing note: modify:

- suppress the first box (and its info on the left)
- eliminate the numbering in the figure and say 1°, 2°, etc. to avoid giving the impression that it refers to specific parts of ISO 14046

- water stress by water scarcity
- change “Choice of water resources used and affected water resources” by “Identification of water …“
- in this rectangle, rephrase saying “Determine the types of elementary flows to be considered, including the types of waters resources from …”
- reorganize the list of second rectangle in parenthesis as such “(e.g., freshwater – including if relevant share of surface water, groundwater, fossil water – brackish water, sea water)”
- in triangle rectangle: inverse water quality and water volume (and replace volume by quantity) and remove the parenthesis
- below triangle: exchange both rectangle to start with quantitative changes
- two last rectangles, change numbering by 1°, 2°, etc.
- before last rectangle: add “impact categories,” before ”category indicators”; and add “(characterization models)” after “water footprint impact assessment methods
- before last rectangle: in the left part, add “, category indicator” after “impact categories”; change “methodologies of impact assessment” by “characterization models”

5.2.2 Determing elementary flows

Editing note: Editing question for English natives: “Determining”, “Determination” or “Identification” or “Identifying”? Then we should align the different sections and the figure.

The procedure for determining the types of elementary flows, is described in ISO 14046, 5.3.2.

At the goal and scope definition phase, site-specific environmental parameters may be based on assumptions or estimates, etc. but should be replaced by more accurate parameters as soon as they are available.

5.2.3 Changes in water quantity and water quality

The procedure for defining relevant changes in water quantity involves estimating the water inputs and outputs illustrated in Figure 2 using readily available data or models. This leads to definition of cut-off criteria (ISO 14046, 3.3.9).

The procedure for defining relevant changes in water quality involves estimating any changes in the water quality parameters and/or characteristics of water inputs and water outputs, as well as emissions to air, water and soil with impact on water quality. Estimates may be based on readily available data or models.

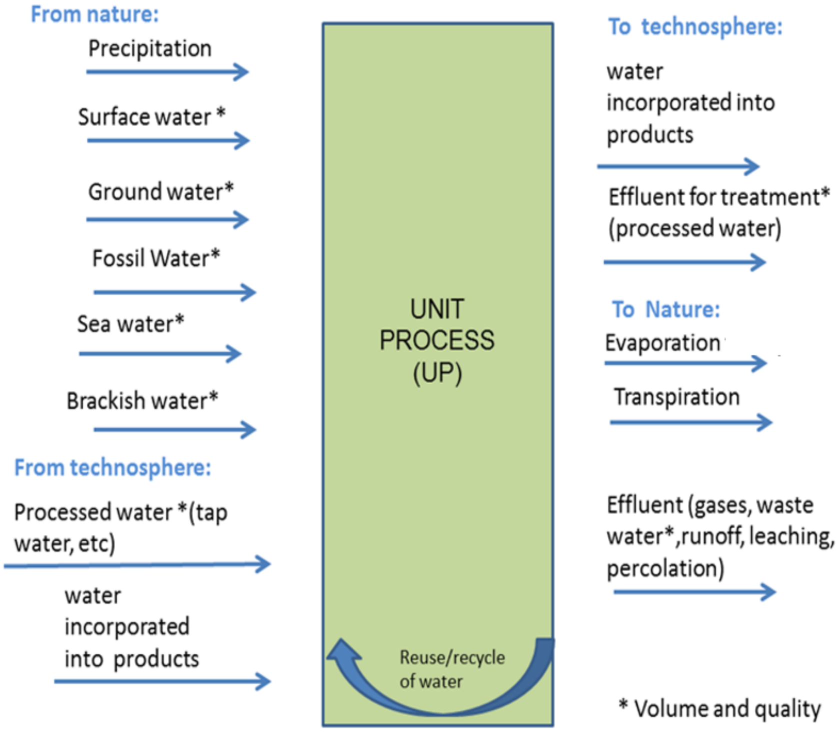


Figure 2 — Examples of water inputs (left) and outputs (right) for a unit process under study

Editing note: Obtain editable version of this figure → Who has the editable version of this figure?

Editing note: Take off "gases"; say "emissions to air, soil and water, heat to water"; Add after "*volume and quality" "(can include heat)"

5.2.4 Determination of impact categories, category indicators and characterization models

In addition to the goal of the water footprint study, the information collected in order to define the system boundary, the type(s) of water resource used and affected water resources, and the associated (quantitative and/or qualitative) changes in water, will assist in determining the appropriate impact categories, category indicators and the characterization models to be considered for the water footprint study – and therefore choice of a type of water footprint.

5.2.5 Choosing the type of water footprint

Based on the information collected, it should be possible to:

— estimate the degree of likely significance (i.e. potential contribution to the water footprint) of each unit process for the study, and therefore which unit processes should become the focus for more detailed data collection;

— specify the data requirements (e.g. primary data, secondary data, estimated data) based on the likely significance of each unit process for the water footprint;

— define the initial cut-off criteria for the study (which are iteratively revisited throughout the study following ISO 14046, 4.5).

Based on this information and general information related to the goal of the study, see ISO 14046, 5.2.1, the type of water footprint that will be a result of the water footprint study can be chosen.

6 Example of water inventory footprint

Editing note: Add a "traditional" example of water inventory footprint?

6.1 Example A - Water footprint inventory analysis of unit processes

Editing note: This is example M in WD3.

6.1.1 Description of water availability – paddy water use in Monsoon Asia

This example refers to rice cultivation with circulative water use as an example of a country in Monsoon Asia for water footprint inventory analysis, which is a representative of moderate rainfall and suitable rice cultivation practices. The highlights of the example are summarized as follows:

a) The example is shown as an exercise of a water footprint assessment by utilizing existing hydrological knowledge, namely the usage of a hydrological model, DWCM-AgWU [1], [2] to analyze water footprint inventory of unit processes (see Figure 1 of ISO 14046).

b) The calculation process contributes to estimate water availability, especially as the note, in which land management (e.g. forestry, agriculture, conservation of wetlands) can modify water availability (e.g. regulating river flows and recharging groundwater).

c) In addition, although water availability is compared to each other in remote locations/regions, the inventory analysis is conducted at a scale and resolution (e.g. a drainage basin, a catchment, or even a sub-catchment).

Editing note: the term "at a scale and resolution" is unclear. To be clarified in India.

The following is an example of a country in Monsoon Asia, representative of moderate rainfall and suitable rice cultivation practices.

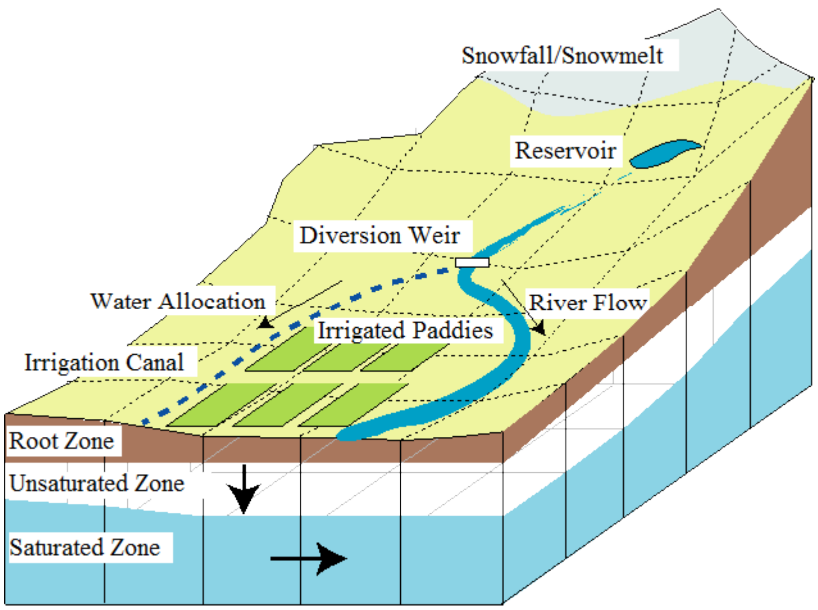


Figure 3 — Depiction of basin-wide processes

6.1.2 Goal and scope definition

The reason to carry out the study in a single process of rice cultivation lies in the fact a model is able to explain the complicated processes in basin-wide water use. The target region is the "Seki" River basin, as an example, which is one of the typical irrigation-dominant basins in a country of Monsoon Asia.

6.1.3 Water footprint inventory

The unit processes are quantified by utilizing a hydrological model, such as DWCM-AgWU, as a scale of drainage basins. This typically applies to situations as described as the basin-wide evaluation of paddy dominant agricultural areas.

Based on the elementary flows which are determined by the water footprint inventory, different methods to determine the water scarcity footprint which are described in other examples of this document can be used. In order to determine the water availability footprint, the water degradation footprint or a water footprint profile, other elementary flows related to water quality have to be determined.

6.1.4 Elementary flows and water circulation

In this approach, a single process in agricultural areas receives rainfall and irrigation water at agricultural facilities (such as diversion weirs in Figure 4 — Necessary components for the water footprint inventory analysis) as inputs, and have evaporation, transpiration and infiltration into groundwater as outputs. In addition, the remaining water, which is not used directly by rice crops, returns to river systems in several points. The elementary flows in an irrigation region are the volumes of the freshwater input including those from residual areas connected to an irrigation region and the freshwater output, at the geographical location of the water body from which the input water is withdrawn and to which the output water is released.

Within the goal and scope definition, it is specified that only freshwater which is usable for irrigation is considered as water input or water output. Furthermore, it is shown that all input water is withdrawn from the location of the process and all output water is released to the location of the process. Part of water output as groundwater gradually returns back into the river systems or sometimes is utilized as the source of drinking water for city dwellers. Indirect inputs and outputs are not considered.

In paddy areas, the source of freshwater differs between rain-fed (precipitation) and irrigated paddies (irrigation water). In both cases, various types of water use exist.

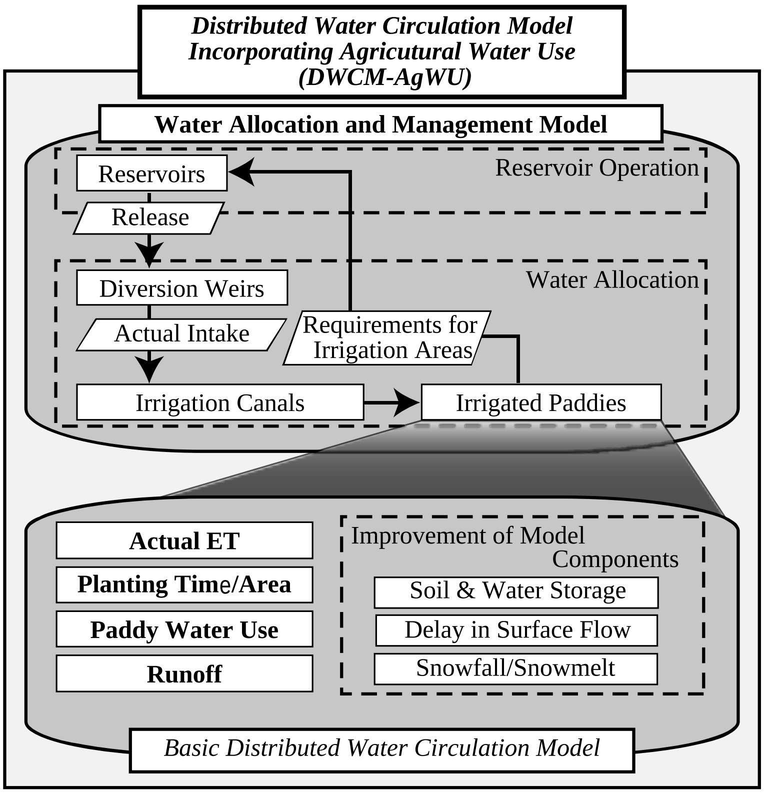


Figure 4 — Necessary components for the water footprint inventory analysis

6.1.5 Calculation procedure of water footprint inventory

For water footprint inventory analyses, the calculation process as shown in Figure 7 is applied. The definition and/or calculation procedure of water footprint inventory proposed in water availability is as follows:

d) The estimation in water footprint inventory of unit process for rice cultivation in paddy areas is carried out in the range of basin (See Figure 7).

e) Each element of water availability, which accounts for rice cultivation and water footprint, is calculated by a model, such as using DWCM-AgWU, which consists of Water Allocation and Management, Actual ET, Planting Time/Area (rice phenology), Paddy Water Use and Runoff models (See Figure 7). [1] [2]

f) Agricultural water use for paddies are divided into rain-fed and irrigated paddies, so that respective water footprint inventory is estimated.

g) The reality of agricultural water use is depicted as the combination of paddy categories in that irrigated paddies are dominant in East Asia, while rain-fed agriculture prevails in the most of South-East Asia. In the paddy-dominant areas with two or three crops within a year, paddies are classified into rain-fed in rainy seasons and irrigated in dry season.

The procedure is applicable to any river basins in monsoon Asia, where intensive irrigation and various types of agricultural water use are carried out.

These results are then summed across the basin (an example in one region of the basin; Tableau 2) and expressed in the units, m^3 H_2Oe / kg brown rice, or m^3 H_2Oe / ha / irrigation period, for example.

6.1.6 Input parameters and calculated results of unit processes

For unit processes, input parameters are land use data, meteorological data, geological & geomorphologic data and celled basin data, while the model estimates planting area of paddies, intake amount, soil moisture and so on related to agricultural water use at arbitrary locations in the basin. It is effective and reliable for assessing the impact of human interactions and/or global warming on basin-wide water circulation and on food production. The model closely fits the observed values, such as discharges of rivers and actual evaporation and transpiration based on observations; therefore, it can provide reliable data in the absence of measured data and un-measured data for its complicity process.

Tableau 2 shows results for the calculation in water footprint inventory analysis for the "Seki" River Basin of a country in Monsoon Asia. The data represent the average of daily calculations for 33 years (1976-2008).

Tableau 2 — Results for the calculation in water footprint inventory analysis

Items	Amount [a] (m^3 H_2Oe / kg)	Ratio of Irrigation Water to Potential Water Availability ($R+Q_{irrig}$)	River Return Ratio ([Return to Rivers]/[Irrigated Water]) [b]
Rainfall (R)	1,649	0,52 (0,74)	0,70
Irrigation water (Q_{irrig})	1,776 (4,593)		
Inflows from residual areas (Q_{res})	(6,491)		
Returns into rivers (Q_{return})	(11,410)		
Infiltration	1,158		
[a] The parenthesis means gross estimations instead of net values. The estimation is carried out in the area (76,3 km^2) of irrigated			

paddy region.

[b] The river return ratio is the combination of daily inputs and outputs considering Q_{res} (37 points) and Q_{return} (23 points) at plural points, which are obtained only by the model calculation.

In this example, as the results of 33 years' average for daily calculations, the single process of "rice cultivation" involves elementary flows of rainfall (888 mm in irrigation periods) and irrigation water (957 mm in irrigation periods) during the cropping period (Tableau 2).

Other elements, determined by DWCM-Ag-WU modelling [1], [2] are evaporation and transpiration from agricultural area (510 mm in irrigation periods), infiltration into groundwater (623 mm in irrigation periods). At the basin scale, by using water allocation and management model [1], the ratio of irrigated water to available water (rainfall and irrigated water) is determined as 0,53 and, in particular, the return ratio of irrigated water into the river system is estimated as 0,70, which shows that most of irrigated water is used for maintaining the water environment in the area and regulating the river flows.

The production of rough rice is 5,39 t ha^{-1} in the region. Although the apparent withdrawal of water for irrigation is 9,570 m^3 ha^{-1} (1,780 l H_2Oe kg^{-1} rough rice), the real consumption is 5,100 m^3 ha^{-1} (946 l H_2Oe kg^{-1} rough rice), or 11,300 m^3 ha^{-1} (2,200 l H_2Oe kg^{-1} rough rice).

Editing note: This last sentence is unclear. To be clarified in India.

In addition, the groundwater recharging function of rice paddies in this particular example is 1160 l H_2Oe kg^{-1} at basin level. What this means is that the production of 1 kg of this rice results in a burden on freshwater systems equivalent to 2100 l of direct water use at the global average water availability index.

The major factor contributing to the water availability footprint, in this example, is irrigation water use. The water availability footprint of this rice cultivation is considered high because the irrigation occurs in addition to rainfall input.

It is important to note that agricultural water, especially in paddy cultivation, should be evaluated in basin scales and that the term of planting time/area should hit the period when less water stress is burdened, and that agricultural water use and/or agriculture is evaluated as having several functions, such as recycle of water for paddy cultivation, groundwater recharge by rice irrigation, reuse for river flow systems instead of being discharged into other areas, such as the ocean/sea.

6.1.7 Bibliography

[1] Yoshida, Takeo, Takao Masumoto, Ryoji Kudo, Tomoyuki Taniguchi and Naoki Horikawa. Modeling of Basin-wide Water Circulation Incorporating Water Allocation and Management Schemes in Large Irrigated Paddy Areas, *Journal of Irrigation, Drainage and Rural Engineering*, 277, 2012, pp.9-19

[2] Masumoto, T., T. Taniguchi, N. Horikawa, T. Yoshida and K. Shimizu. Development of a distributed water circulation model for assessing human interaction in agricultural water use, M. Taniguchi, W.C. Burnett, Y. Fukushima, M. Haigh & Y. Umezawa (Eds.), *"From Headwaters to the Ocean: Hydrological Changes and Watershed Management,"* 2009, Taylor and Francis, pp.195-201

7 Examples of single impact category

7.1 Example B – Water scarcity footprint of different water supply options

Editing note: This is example D in WD3.

7.1.1 General

The purpose of this fictive example is to show the application of the concept of water scarcity footprint.

A water utility is investigating the water scarcity footprints of three options (A, B and C) for the supply of 100 m^3 of water to a user in the industrial sector (being therefore the functional unit (FU)). The boundaries of the system are illustrated in Figure 5 showing where water is extracted from the environment and returned to the environment.

The three options for supply of water are:

A : Freshwater from Region X, a region with high water scarcity

B : Freshwater from Region X + Freshwater from Region Y. Region Y is a region with relatively low water scracity

C : Freshwater from Region X + Reuse water from treated wastewater.

The elementary water flows are the freshwater withdrawn by the reservoir(s) (runoff and rainfall), losses through evaporation and treated used water discharged to the sea. Water output for reuse is not considered as an elementary water flow.

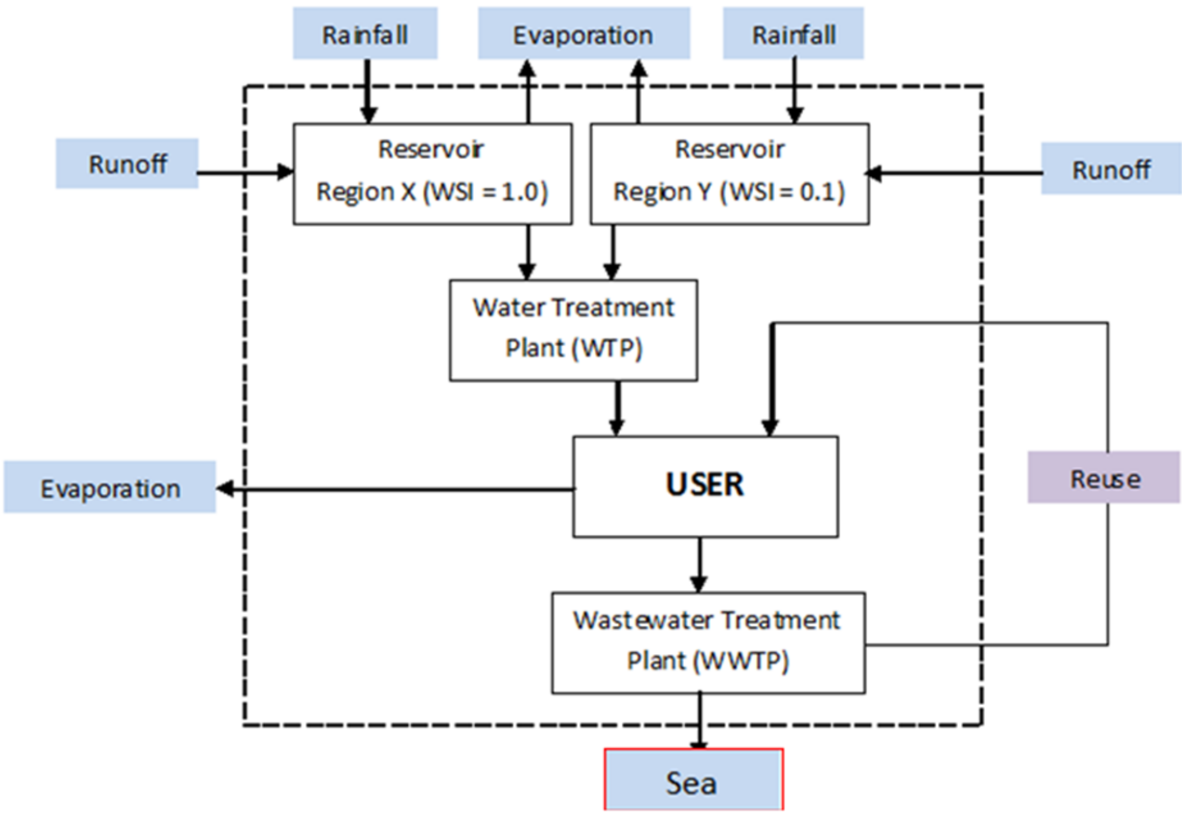


Figure 5 — Option for the supply of water to user (including the characterization factor for local water scarcity for each unit process where water consumption occurs)

Editing note: Obtain editable version of this figure → Who has the editable version of this figure?

Editing note: Put the reuse inside the system boundary; Change “(WSI = …)” by “(high water scarcity)” and “(low water scarcity)”.

7.1.2 Inventory

The inventory is shown in Tableau 3. For simplicity, other flows such as losses at the WTP and in the distribution network are not considered. A life cycle inventory using background databases shows that treating treated used water to the level that can be returned to user as well as the associated infrastructure and energy consumes 1 m^3 per 10 m^3 reused water[1]. The location Z of this water consumed is unknown and is therefore assumed to be at the global average characterization factor for water scarcity.

Tableau 3 — Inventory of the different options (in m^3/FU)

Line #		Option A	Option B		Option C	
	Region	X	X	Y	X	Z
1	Sum of Runoff and Rainfall	111	71	40	71	
2	Reuse water	-	-	-	36	
3	Evaporation from reservoir	11	7	4	7	
4	Water to WTP	100	64	36	64	
5	Water to USER	100	64	36	100	
6	User’s net water consumption	30	19.2	10.8	30	
7	Used water to WWTP	70	44.8	25.2	70	
8	Treated wastewater to sea	70	44.8	25.2	34	
9	Water consumed associated with the reuse (treating treated used water to the level that can be returned to user as well as the associated infrastructure and energy)	-	-	-		3.6

7.1.3 Impact assessment

The water scarcity footprint is calculated as the water consumed multiplied by the characterization factor for scarcity (being here, for example, the method of WULCA [1], where the characterization factor is called “user deprivation potential”) for each region where water consumption occurs (indicated in Figure 5). Note that the global average characterization factor for water scarcity is by definition 1 in the WULCA method [1].

7.1.4 Water scarcity footprint results

The results, after impact assessment, are shown in Tableau 4.

Tableau 4 — Results

[1] Fictive values for the sake of the example. Do not reuse.

	Option A	**Option B**		**Option C**	
Region	X	X	Y	X	Z
Net water consumption (m^3) (lines 3+6+8+9)	111	71	40	71	3.6
Characterization factor for the local water scarcity (called "user deprivation potential" in this method) of that region ([1])	100	100	0.5	100	1
Water scarcity footprint (m^3 H2Oe)	**111*100 = 11100**	**71*100 = 7100**	**40*0.5 = 20**	**71*100 = 7100**	**3.6*1 = 3.6**
Water scarcity footprint (m^3 H2Oe)	**11100**	**7100 + 20 = 7120**		**7100 + 3.6 = 7103.6**	

The results of this fictive example show that option C has the lowest water scarcity footprint, followed closely by option B. However, the differences between the water footprint results of alternative products, processes or organizations may not always be significant. In fact, in this example, when considering uncertainties associated with inventory values and especially the characterization factors for local water scarcity (i.e., the user deprivation potentials), it is fair to assume that in this fictive example options B and C have a similar water scarcity footprint but below the one of option A.

Note also that whether the water is evaporated at the user or discharged into the sea does not make a difference: it is in both cases considered not returned in a state of freshwater to the environment. However, in this case, the impacts related to water scarcity occur at the place of water withdrawn and not where the water is evaporated or released into the sea.

7.1.5 Bibliography

[1] WULCA (2015). Presentation at the Annual meeting SETAC Europe, Barcelona, Spain May 7th, 2015. Available at http://www.wulca-waterlca.org.

7.2 Example C – Water scarcity footprint of an agricultural product in two different locations

Editing note: This is example A in WD3.

7.2.1 Introduction

This illustrative fictive example describes the calculation of the water scarcity footprint of an agricultural product (here rice is used as an example) in two different locations, one with high and one with moderate water scarcity.

The purpose of this example is to show the application of the concept of water scarcity footprint and show that different methods exist providing different results, something important to keep in mind when selecting and applying a specific method.

7.2.2 Life cycle inventory

7.2.2.1 Elementary water flows

In this example, we assume that the life cycle inventory is the same in both cases. The unit process "rice cultivation" involves elementary flows of rainfall (0,63 ML ha^{-1}) and surface water used for irrigation (9,9 ML ha^{-1}) during the cropping period (Figure 6). Other flows, determined by APSIM [1] modelling, are evaporation from pond (3,2 ML ha^{-1}), transpiration (6,4 ML ha^{-1}) and drainage to saline coastal groundwater (0,93 ML ha^{-1}) [4]. At the larger spatial scale, encompassing many individual rice fields, sideward flows between individual rice fields are disregarded. APSIM modelling was also used to determine that no deep drainage occurs under a scenario without rice cultivation and irrigation.

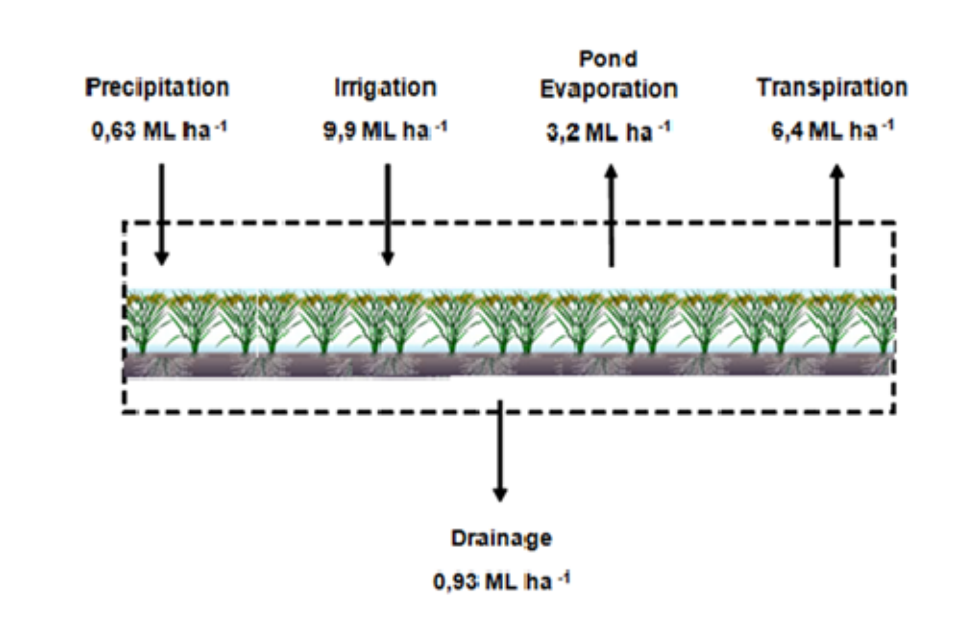


Figure 6 — Elementary flows of water in the rice cultivation example

7.2.2.2 Material inputs

Rice cultivation also uses a variety of material inputs (e.g. fuels, fertilizers and other agricultural chemicals). The water consumed to manufacture the material inputs used to cultivate 1 ha of rice field was estimated as 0,012 ML based on best available data from a data provider. The location of water use for the production of these material inputs was unknown.

7.2.2.3 Products

The production of rough rice is 8,7 t ha^{-1} at farm gate.

7.2.3 Water scarcity footprint calculation

The input of freshwater for irrigation is 9,9 ML ha^{-1} (1134 L kg^{-1} rough rice).

The rice cultivation system results in an increase of drainage (0,93 ML ha^{-1}). However, this drainage is to saline coastal groundwater and is therefore no longer useable as freshwater.

The freshwater consumed in the manufacture of material inputs (0,012 ML ha^{-1} or 1,4 L kg^{-1} rough rice) occurs at an unknown location. Estimating that the unknown location has more likelihood to be within the country than outside the country, the national average water scarcity of location A and location B is applied.

To calculate the water scarcity footprint, each instance of water consumed is multiplied by the relevant characterization factor for water scarcity, being either the local water scarcity index or the average national scarcity index, depending on whether one knows the exact location or simply which country one is. These results are then summed across the product life cycle (from cradle to farm gate in this case; Tableau 5) and expressed in the units H_2Oe (equivalents).

Tableau 5 — Water scarcity footprint calculation

	Life cycle stage	Water consumed (L/kg of rice)	Characterization factor (in amount per amount and therefore unitless) considered (at the watershed level for irrigation; at the country level for material and energy inputs) for the impact assessment method for water scarcity footprint by:						Water scarcity footprint (L H_2Oe/kg of rice)					
			[2] (called user deprivation potential in this method)	[3] (called water stress index in this method)	[4] (called scarcity in this method)	[5] (called water stress index α in this method)	[6] (called water scarcity indicator in this method)	[7] (called water deprivation index in this method)	[2]	[3]	[4]	[5]	[6]	[7]
Location A in country X	Irrigation (location A)	1134	50	1.00	8.00	1.00	4.00	1.00	56700	1134	9072	1134	4536	1134
	Material and energy inputs (country X)	1.4	257	0.40	0.04	0.71	3.77	0.91	360	0.56	0.056	1	5.278	1
	Total	-	-	-	-	-	-	-	57060	1134.56	9072.056	1135	4541.278	1135
Location B, in country X	Irrigation (location B)	1134	10	0.01	0.002	0.00	1.25	1.00	11340	11.34	2.268	0	1417.5	1134
	Material and energy inputs (country X)	1.4	257	0.40	0.04	0.71	3.77	0.91	360	0.56	0.056	0.994	5.3	1
	Total	-	-	-	-	-	-	-	11700	11.9	2.324	0.994	1422.8	1135

In this particulate example, the water scarcity footprint of rice at farm gate is presented in the “total” line. For example, considering the approach of [1], the water scarcity footprint is 568 L H_2Oe/kg.

Some methods (such as [8]) suggest expressing the results in relation to the global average water scarcity. For example, the results presented using [2] can be divided by the average global water scarcity index which is 0.6 for this specific method. In that case, the water scarcity footprint od rice found in Tableau 5, which is 1135 L H_2Oe/kg of rice for location A, would be transformed to 1890 L H2Oe/kg of rice. In that specific case, this means that the production of 1 kg of this rice results in a burden on freshwater systems equivalent to 1890 L of direct water consumption at the global average water scarcity index of method [2].

In this fictive example, one observes that the major factor contributing to the water scarcity footprint is irrigation. It is important to note that this example is not representative of rice production generally.

7.2.4 Bibliography

[1] Keating, B.A. et al. An overview of APSIM, a model designed for farming systems simulation. *Eur. J. Agron.*, 18(3-4), 2003, pp. 267-288

[2] WULCA (2015). Presentation at the Annual meeting SETAC Europe, Barcelona, Spain May 7th, 2015. Available at http://www.wulca-waterlca.org.

[3] Pfister, S., Koehler, A. and Hellweg, S. Assessing the environmental impacts of freshwater consumption in LCA. *Environ. Sci. Technol.*, 43(11), 2009, pp. 4098-4104. Water stress indexes available on a google earth layer at http://www.ifu.ethz.ch/ESD/downloads/EI99plus.

[4] Frischknecht R., Steiner R. and Jungbluth N. (2008): The Ecological Scarcity Method – Eco-Factors 2006. A method for impact assessment in LCA. Environmental studies no. 0906. Federal Office for the Environment (FOEN), Bern. 188 pp. (as implemented in PEF/OEF). Water stress indexes available on a google earth layer.

[5] Boulay, A.-M.; Bulle, C.; Bayart, J.-B.; Deschenes, L.; Margni, M. Regional Characterization of Freshwater Use in LCA: Modeling Direct Impacts on Human Health Environmental Science & Technology 2011, 45, 8948-8957. Water stress indexes available on a google earth layer at http://www.ciraig.org/fr/wateruseimpacts.php

[6] Hoekstra AY and Mekonnen MM (2011). Global water scarcity: the monthly blue water footprint compared to blue water availability for the world's major river basins. Value of water research report series No 53. September 2011. UNESCO-IHE Institute for Water Education, P.O. Box 3015 , 2601 DA Delft, The Netherlands.

[7] Berger M, van der Ent R, Eisner S, Bach V, and Finkbeiner M (2014). Water Accounting and Vulnerability Evaluation (WAVE): Considering Atmospheric Evaporation Recycling and the Risk of Freshwater Depletion in Water Footprinting. Environ. Sci. Technol. 48, 4521−4528. Water stress indexes available on a google earth layer.

[8] Ridoutt, B.G. and Pfister, S. A revised approach to water footprinting to make transparent the impacts of production and consumption on global freshwater scarcity. Global Environ. Chang., 20(1), 2010, pp. 113-120.

7.3 Example D – Water scarcity footprint of a reservoir, reflecting seasonality

Editing note: This is example C in WD3.

7.3.1 Description of the example and water footprint inventory

This is a fictitious example. It demonstrates the importance of the seasonality approach in specific cases.

The goal of the study is to determine the water scarcity footprint of a reservoir as a process, taking into account seasonality of flows and of water scarcity. The function of the reservoir is to supply water in controlled quantities for different uses, i.e. generation of hydropower, irrigation and municipal water supply. This includes retaining water from the wet season (November – March) in order to be usable in the dry season (April – October).

The reservoir covers a surface area of 20 km^2, in a semi-arid region. Average annual evaporation and annual transpiration from local vegetation prior to the construction of the dam is equal to annual average precipitation (500 mm/a, i.e. 10 Mm^3 for 20 km^2). However, following construction of the dam, evaporation from the reservoir surface increases to 1500 mm/a, i.e. 30 Mm^3 for 20 km^2. This means that the total annual water loss by human activity is 20 Mm^3/a.

The reservoir has a constant outflow rate throughout the year. The water inflow, before and after the construction of the dam was identical. The local annual characterization factor for water scarcity is 0.38.

Tableau 6 shows the annual variation in the water balance of the 20 km^2 area before (baseline) and after (with reservoir).

Tableau 6 - Annual variation in the water balance of a reservoir (Mm^3/a)

	Baseline	With reservoir	Reduction in outflow
Inflow	630.7	630.7	-
Precipitation	10.0	10.0	-
Evaporation	10.0	30.0	
Outflow	630.7	610.7	20.0

The functional unit is one year of activity of the reservoir.

The seasonality is reflected by determining the water inputs and the water outputs on a monthly basis (Tableau 7). The monthly water consumption of the dam, i.e. the 7th column of Tableau 7, is calculated as the difference between water inflow to the reservoir and the water outflow from the reservoir.

The water volume in the reservoir is reduced from the maximum value of 312 Million m^3 at the end of the rainy season to a minimum value of 117 Million m^3 at the end of the dry season.

7.3.2 Impact assessment

When the seasonality and the positive effect of the reservoir on water scarcity are taken into account, then the fact that water is retained in the reservoir during the wet season and released for irrigation and municipal water supply during the dry season has to be considered, taking into account the data as presented in Tableau 7. For this purpose, the characterization factor assessing water scarcity (the water scarcity index (WSI)) has been determined on a monthly basis, according to [1] and [2]. For the calculation of the water scarcity footprint, equation (2) has been applied on a monthly basis. For the calculation of the annual water scarcity footprint, the monthly values have been added up (equation 3).

$$WF_{Sc,n} = (V_{r,in} - V_{r,out}) \times \frac{CF_{Sc,L,n}}{CF_{Sc,Glo}} \quad (2)$$

$$WF_{Sc} \quad \sum_{n=1}^{12} WF_{Sc,n} \quad (3)$$

where

$WF_{Sc,n}$	is the monthly water scarcity footprint of the month n
$(V_{x,in} - V_{x,out})$	is the water flow balance in the reporting month n
$CF_{Sc,L,n}$	is the monthly water scarcity index at the location of the reservoir in the reporting month n
$CF_{Sc,Glo}$	is the global average water scarcity index i. e. 0,6

Editing note: To decide in India whether there is value to introduce the normalization by the world average here for the sake of the example or better stick to the absolute WSI to avoid introducing two issues in one example.

WF_{Sc}	is the water scarcity footprint of the reservoir based on seasonality

Tableau 7 - Elementary flows and impact assessment

Reporting month	Water inflow $V_{x,in}$	Evapor-ation $V_{x,Evap}$	Preci-pitation $V_{x,Precip}$	Water outflow $V_{x,out}$	Water volume in reservoir V_x	Water flow balance $V_{x,in}$ $V_{x,o}$	Monthly charact. factor $\frac{CF_{Sc,L,n}}{CF_{Sc,Glo}}$	WSFP $WF_{Sc,n}$
	Mm^3/month	Mm^3/month	Mm^3/month	Mm^3/month	Mm^3/month	Mm^3/month		Mm^3 H_2Oe
January	100,0	0,2	1,0	50,9	249,9	49,1	0,05	2,5
February	100,0	0,2	2,0	50,9	300,8	49,1	0,05	2,5
March	60,0	0,5	2,3	50,9	311,8	9,1	0,2	1,8
April	40,0	1,5	2,0	50,9	301,4	-10,9	0,3	-3,3
May	45,7	3,0	1,3	50,9	294,5	-5,2	0,4	-2,1
June	10,0	6,0	0,3	50,9	248,0	-40,9	0,7	-28,6
July	10,0	7,0	0,1	50,9	200,2	-40,9	0,9	-36,8
August	10,0	6,0	0,1	50,9	153,4	-40,9	0,9	-36,8
September	20,0	4,0	0,1	50,9	118,5	-30,9	0,7	-21,6
October	50,0	1,0	0,1	50,9	116,7	-0,9	0,2	-0,2
November	85,0	0,3	0,2	50,9	150,7	34,1	0,1	3,4
December	100,0	0,3	0,5	50,9	200,0	49,1	0,05	2,5
Total	**630,7**	**30,0**	**10,0**	**610,7**		**20,0**	**0,38**	**-117**

In Tableau 7, a monthly water scarcity footprint is calculated which results in positive figures in the wet season where more water is collected in the reservoir than released, and negative figures in the dry season where more water is released than collected.

Because of the different water scarcity indexes, the sum of the monthly water scarcity footprints is a negative figure, i.e.

$$WF_{Sc,n} = -117\ Mm^3\ H_2Oe/a.$$

This value indicates that the positive effect of the reservoir due to retaining the water of the wet season for irrigation and municipal water supply in the dry season is much higher than the negative effect due to evaporation and reduced flow during wet season.

7.3.3 Importance of the seasonality approach

Without consideration of seasonality, the water scarcity footprint would have been simply the net amount of water evaporated (20 Mm^3/a) multiplied by the local annual average characterization factor (being here 0.38/0.6 = 0.63) which results in a water scarcity footprint of 13 Mm^3 H_2Oe/a.

7.3.4 Allocation

The question remains how to allocate the water scarcity footprint of the reservoir to the downstream processes, i.e. electricity generation, irrigation and municipal water supply. No further guidance is given here how to solve the allocation issue, as this requires further information about the local conditions.

7.3.5 Final remark

A reservoir may have other environmental impacts than creating increasing or decreasing water scarcity (such as degradation of fisheries, sedimentation and erosion problems arising from the construction of reservoirs and changes in the hydrological regime, impacts on biodiversity and degradation of the water quality). In order to address such additional impacts, a comprehensive set of impact categories in addition to water scarcity, needs to be worked out. Details about methodology and possible results are not presented here.

7.3.6 Bibliography

[1] Pfister S. and Baumann J. Monthly characterization factors for water consumption and application to temporally explicit cereals inventory, Paper presented at the 8th International Conference on LCA in the Agri-Food Sector, Rennes, France 2012,

[2] Pfister S. and Bayer P. Monthly water stress: spatially and temporally explicit consumptive water footprint of global crop production, *Journal of Cleaner Production* 73(0), 2014, pp. 52-62

7.4 Example E – Water scarcity footprint versus water availability footprint

Editing note: This is example G in WD3.

This example aims at showing the difference between the concepts of water scarcity footprint and water availability footprint (see ISO 14046, section 5.4.5).

This example is for illustrative purposes of method application. While data and model used are available and operational, it does not represent a real case study and the geographical location is chosen arbitrarily to represent one with relatively high water scarcity and relatively low socio-economic resources.

7.4.1 Description of the case – production of a packaging material

In an area X, a production process for 1 t of a specific packaging material with the water input/output data and emissions to water according to **Fehler! Verweisquelle konnte nicht gefunden werden.** is occurring. The chemical composition of the incoming water is unknown, but in this region, available water is assumed to be suitable for standard potable water supply. **Fehler! Verweisquelle konnte nicht gefunden werden.** describes the water footprint inventory for the water-related flows at the site level.

Tableau 8 — Collected inventory data for 1 t of a specific packaging material production (only site specific inventory, not showing the supply chain)

		Input or output		**Concentration in output water**	
Surface water input		38	m^3		
Surface water output		37	m^3		
Quality parameters of output water	BOD (5 days)	3,4	kg	93	mg/l
	COD	12	kg	329	mg/l
	TOC	1,9	kg	52	mg/l
	Nitrogen	0,2	kg	5,5	mg/l
	Phosphorus	0,038	kg	1,04	mg/l
	Suspended solids, unspecified	2,3	kg	63	mg/l

NOTE This only account for direct water use and emissions at the factory but not for indirect water use and emissions associated with input materials of energy or treatment of waste exported from the factory.

7.4.2 Goal and scope definition

Two different types of water footprint results are calculated in order to illustrate the application of various aspects of the standard:

1) Water scarcity footprint: The purpose of a water scarcity footprint is to give an assessment of the contribution of the product, process or organization to water scarcity. Water scarcity considers only water quantity and not how degradation affects its availability to users (see ISO 14046).

2) Water availability footprint: This result represents impacts from lower water availability due to water consumption and degradation.

7.4.3 Direct water scarcity footprint

For this assessment, the method provided in [1] is used in the simplified version provided online (*http://www.ciraig.org/wateruseimpacts.php*). This method provides scarcity indicators, based on consumption-to-availability ratio and modelled to result in an index between 0 and 1.

Editing note: the term “scarcity indicators” used here is called “water stress index α” in the google earth layer. To clarify what the correct term to use.

NOTE The water stress index as reported in Example A is based on the withdrawal-to availability ratio.

They cover the entire globe and are made available on a Google Earth Layer. It is available for the use of surface or ground resource. When the input resource is unknown, the “unspecified” data can be used as it is a weighted average of surface and ground water indicators based on the withdrawal fraction of each resource. The parameters can be used to calculate the scarcity footprint with the following equation:

$$W_{\mathrm{SC}} = V_{\mathrm{in}} \cdot CF_{\mathrm{Sc,in}} - V_{\mathrm{out}} \cdot CF_{\mathrm{Sc,out}} \qquad (12)$$

where

WF_{Sc} is the water scarcity footprint,

V_{in} is the volume of water which enters the system,

$CF_{Sc,in}$ is the water scarcity index at the location where the water enters the system,

V_{out} is the volume of water which leaves the system, and

$CF_{Sc,out}$ is the water scarcity index at the location where the water leaves the system.

In this example, the input volume of 38 m^3 is from surface, and water released of 37 m^3 is to the surface as well. The water scarcity index for surface water in region X is equal to 0.45 m^3 H_2Oe/m^3 consumed. Since 1 m^3 of water is consumed, and there is no change of water source between surface and ground water, the result of the “direct” water scarcity footprint to produce 1 t of that specific packaging material is therefore: 1 m^3 consumed x 0.45 m^3 H_2Oe/m^3 consumed = 0.45 m^3 H_2Oe.

7.4.4 Direct water availability footprint

The water availability footprint accounts for the water stress generated by a human activity. It allows an evaluation of how other water users would potentially be deprived from these resources if they are consumed or degraded to a point beyond functionality.

Similar to the indicator results of other impact categories, the water availability footprint of a unit process is calculated as:

$$WF_{\mathrm{av}} = \sum_i CF_{av,i} \cdot V_i \qquad (13)$$

where

WF_{av} is the water availability footprint,

V_i is the volume of the water input (when positive figure) or water output (when negative figure), and

$CF_{av,i}$ is the characterization factor for each V_i, which can be obtained for each water category (i) here: *www.ciraig.org/wateruseimpacts.*

The factor $CF_{av,i}$ is a quality-adjusted index, which is based on the ratio between net water consumption and water availability. It is specific for each water category, range from 0 to 1, and is regionalized by drainage basin or country. Calculations details can be obtained from [1].

For the water availability footprint, the quality of water inputs and water outputs is considered by defining water categories. For each water category, the local water stress is based on the water availability and the net water consumption within the relevant region. This approach is based on the definition of the water categories presented in [2] and shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Tableau 9 — Qualitative definition of water categories. For quantitative values of contaminants for each category [2]

Editing note: The sentence "For quantitative values of contaminants for each category [2]" is unclear. To clarify.

Excellent	Good	Average	Average-Tox	Average-Bio	Poor	Very Poor	Unusable
1	2a	2b	2c	2d	3	4	5
low coliforms, low toxic	low coliform, medium toxic	medium coliform, medium toxic	low coliform, higher toxic	high coliforms, low toxic	high coliform, medium toxic	high coliform, high toxic	other - unusable

Assessing the water category of the input and output flows allow the calculation of the water availability footprint. This can be performed based on available data in different ways, from the less data-intensive alternative to the most:

h) Default and qualitative assessment: based on geographical location, default input water quality category can be obtained from [2]. Output water quality category can be based on the qualitative assessment presented in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

i) Default and generic assessment: based on geographical location, default input water quality can be obtained from [2]. Output water quality category can be assessed using reported industry effluent standards and the tool provided online (*http://www.ciraig.org/wateruseimpacts*).

j) Specific assessment: primary data can be used for input and/or output water quality and the relevant category assessed using the online tool above.

In the present example the elementary flows are described by

— the volume of the water input and water output;

— the type (ground water or surface water) and geographical location of the water body from which the input water is withdrawn or to which the output water is released (here to surface);

— the quality of the input water is not known but as per definition in [2] and knowing that the local water can be potabilized by a standard treatment, the input water quality is set to 2a. Alternatively, this can be verified using the default water qualities of water available world-wide as published in [XX];

— the output water quality is assessed using specific effluent data (see **Fehler! Verweisquelle konnte nicht gefunden werden.**) and using the water category definition [2] or online tools (www.ciraig.org/wateruseimpacts). It is assessed to be of category 5.

More detailed criteria for the distinction of the different water categories, based on their biological and chemical composition, are described in [2].

It is considered that the less functional a water category is, the more abundant it will be, since all higher quality categories will also meet the functionality requirements of this category. This is a consequence of water categories being defined by upper thresholds of a contaminant concentration instead of ranges, as they are functionality-based. For example, water of category 3 would also include water of category 2 and 1, and so on.

In the present example, the characterization factor $CF_{av,2a}$ for the water category 2a in the relevant region is 0.86, and for category 5 the characterization factor $CF_{av,5}$ is 0 (as polluted water is more abundant than good quality water). Then the resulting direct water availability footprint W_{AF} is:

$$W_{AF} = \left(0{,}86 \cdot 38\text{m}^3\right) - \left(0 \cdot 37\text{m}^3\right) = 32{,}5\text{m}^3 \text{ water eq.}$$

7.4.5 Possible double counting

When the indicator of water availability footprint, as presented in this example, is used in a comprehensive water footprint, it should be understood that there may be double counting of impacts on human health, as either toxicity impacts or (un)availability impacts may occur. Alternatively, the water scarcity footprint can be used instead of the water availability footprint in a complete profile.

7.4.6 Bibliography

[1] A.-M. Boulay, C. Bulle, J.-B. Bayart, L. Deschenes, and M. Margni, “Regional Characterization of Freshwater Use in LCA: Modeling Direct Impacts on Human Health,” Environmental Science & Technology, vol. 45, no. 20, pp. 8948–8957, 2011.

[2] A.-M. Boulay, C. Bouchard, C. Bulle, L. Deschênes, and M. Margni, “Categorizing water for LCA inventory,” The International Journal of Life Cycle Assessment, vol. 16, no. 7, pp. 639–651, 2011.

7.5 Example F – Water scarcity footprint using characterization factors based on global mean precipitation

7.5.1 Introduction

Editing note: This was example B in WD3.

The purpose of this example is to show …XXX precise here what XXX….

Since water resources have uneven distributions with place and source of water, the potential impacts of water use can also be different by place and source of water, even if the same amount of water is consumed in different situations. In this example, water footprint inventory is characterized into the category indicator result "water scarcity footprint" by characterizing the water availability of each water source based on hydrological water balance.

7.5.2 Goal and scope definition

7.5.2.1 Goal of the study

This example is intended to show a case study of water footprint impact assessment for wheat production to water scarcity. This study is a stand-alone assessment of water scarcity footprint.

7.5.2.2 Scope of the study

In this study, the following items are defined as the scope;

k) system boundary: determined for wheat production only in agriculture

l) functional unit: production of 1 kg of wheat (edible portion)

m) temporal resolution: a year, geographical coverage: location A (36.26°N, 119.75°W) and B (48.25°N, 1.75°E) *The irrigated cropland area in [1] and the crop type data [2] are adopted.

n) data and data quality requirements:

  — quantities of water used

  — types of water resources used (surface water and groundwater)

o) cut-off criteria: water use for fertilizers, pesticides, and machines production

p) allocation procedures: not considered because the scope has no co-products

q) assumptions, value choices and optional elements: water footprint impact assessment is conducted at the characterization level only; weighting is not included

r) water footprint impact assessment methodology: characterization factor in [3] and [4] adopted for water footprint impact assessment; type of impact category assessed: water scarcity

s) whether the results of the water footprint assessment will include one impact indicator result (and specifying which one), a water footprint profile, and/or a water footprint after weighting: include one impact indicator result of water scarcity.

t) whether the water footprint assessment is comprehensive: not comprehensive

u) which cause effect chains and impacts are covered by the water footprint assessment and identify the foreseen consequences of the excluded impacts: Water footprint impact assessment from water use to change of freshwater availability is included as midpoint of cause effect chains, considering the difference of water resources by place and source of water. Endpoints such as human health, social problems, and biodiversity are excluded consequences in this study

v) uncertainties and limitations: A water footprint assessment alone is insufficient to be used to describe the overall potential environmental impacts of the wheat production. Decisions about impacts that are only based on a single environmental issue can be in conflict with goals and objectives related to other environmental issues.

w) justifications for exclusions from the study: It is known that water use for fertilizers, pesticides, and machines production is small compared with plantation.

x) baseline conditions with which the current conditions caused by the activities are being compared if applicable: not considered.

y) reporting: none

z) type of critical review: none

7.5.3 Water footprint inventory analysis

7.5.3.1 Water footprint inventory calculation

As the water footprint inventory for wheat production in each country, we applied the result in [5], which calculated the water use for wheat production in each country by considering water sources based on a global water resource model. In this study, used water from rivers and medium-size reservoirs are applied for surface water, and nonrenewable and nonlocal blue water is applied for groundwater.

7.5.3.2 Elementary flows

The elementary flows are described by:

aa) quantities of water used:

  — volume of evapotranspiration

bb) resource types of water used:

— surface water;

— groundwater

cc) water quality parameters and/or characteristics: not considered

dd) forms of water use;

— evapotranspiration;

ee) geographical location of water use or affected: the representative irrigated cropland for wheat production at location A (36.26°N, 119.75°W) and location B (48.25°N, 1.75°E) at 0.5 × 0.5 degrees spatial resolution

ff) temporal aspects of water use:

— supply and demand calculation on daily basis during the cropping periods

gg) emissions to air, water and soil with impact on water quality: not considered

7.5.4 Water footprint impact assessment

7.5.4.1 General

Impacts related to water use are represented by one parameter which quantifies the potential environmental impacts of wheat production system by water scarcity footprint.

7.5.4.2 Selection of impact categories, category indicators and characterization models

Water use occupies water resources that can be diverted to other uses, and so can result in reduced local water availability. In this study, local water scarcity is chosen as an impact category reflecting the differences of water availability by place and source of water.

7.5.4.3 Characterization

7.5.4.3.1 General

The characterization factors in [3] and [4] are applied in the water footprint impact assessment. This method provides characterization factors for each water source (surface water and groundwater), reflecting the differences of water availability. The characterization factors are available online at http://hydro.iis.u-tokyo.ac.jp/data/WFP/.

7.5.4.3.2 Geographical and temporal issues in characterization

The local characterization factors are calculated as follows:

$$CF_{SC,Sw} = \frac{A_{Sw}}{A_{ref}}\ ;\ CF_{SC,Gw} = \frac{A_{Gw}}{A_{ref}} \qquad (1)$$

where

A_{ref} is the required area to obtain the reference volume of water from the reference condition [m^2]

Editing note: Should we say “per year” somewhere here?

$CF_{Sc,Sw}$ is the local characterization factor for surface water [m^2/m^2 = unitless]

A_{Sw} is the required area to obtain the reference volume of surface water per year [m^2]

$CF_{Sc,Gw}$ is the local characterization factor for groundwater [m^2/m^2 = unitless]

A_{Gw} is the required area to obtain the reference volume of groundwater per year [m^2]

Since the global mean precipitation approximates 1000 mm per year, 1 m^3 of precipitation over an area of 1,0 m^2 is proposed as the reference condition in this study. More details about the framework of the characterization factor is described in [3] and [4]. In this example, the local characterization factors of a process at a specific geographical location are determined as shown in Tableau 10:

Tableau 10 — Local characterization factors for different water sources in location A and B

	Water source	Annual rate of hydrological cycle (mm/year)*	Required area - A_{SW}, A_{GW} (m^2)	Required area, reference - A_{ref} (m^2)	Local characterization factor (m^2/m^2)
Location A	Surface water	156	6,4	1,0	6,4
	Groundwater	131	7,6	1,0	7,6
Location B	Surface water	328	3,0	1,0	3,0
	Groundwater	263	3,8	1,0	3,8

* The annual rate of surface and groundwater is calculated based on the calculation by using H08 model [3]. This model makes it possible to calculate global water cycle with the natural hydrological cycle and human activities, such as reservoir operations and irrigation activities, with the environmental flow requirements. The total runoff result is applied for the rate of surface water, and the result of subsurface runoff is applied for the rate of groundwater. The simulation setting was identical to [4], except for the meteorological forcing and calculation period. The WATCH forcing data [5] was used for meteorological forcing, and water use was simulated, based on the daily water supply and demand for 1991–2000.

7.5.4.4 Water scarcity footprint

The water scarcity footprint, expressed in amount of water equivalent [m^3 H_2Oe], (WF_{SC}) is calculated as the sum of two characterization results as follows:

$$WF_{SC} = C_{Sw} \times CF_{SC,Sw} + C_{Gw} \times CF_{SC,Gw} \quad (3)$$

where

C_{Sw} is the water use from surface water [m^3]

$CF_{SC,Sw}$ is the local characterization factor related to surface water [m^2/m^2]

C_{Gw} is the water use from groundwater [m^3]

$CF_{SC,Gw}$ is the local characterization factor related to groundwater [m^2/m^2]

7.5.5 Limitations of water footprint

In this study, water scarcity footprint assessment is addressed on the potential impacts in regard to water quantity, not including water degradation. This is insufficient to be used to describe the overall potential environmental impacts of products. Decisions about impacts that are only based on a single environmental issue can be in conflict with goals and objectives related to other environmental issues. It is possible that the local characterization factors have uncertainty with meteorological data or a water resource model.

7.5.6 Results

Tableau 11 shows results of water footprint impacts assessment for water scarcity related to wheat production in location A and location B. In location A, characterization factors for each water source are higher than location B due to the hydrological features. The water scarcity footprint of wheat produced in location A is also higher than location B.

Tableau 11 — Example of life cycle impact assessment for wheat production in location A and B

	Water source	Yield (t of wheat / ha)	Water footprint inventory (m^3 / t of wheat)	Local characterization factor (m^2 / m^2)	Water scarcity footprint (m^3 H_2Oe / t of wheat)
Location A	Surface water	-	111	6,4	710
	Groundwater	-	149	7,6	1132
	Total	2,83	260	-	1842
Location B	Surface water	-	14	3,0	42
	Groundwater	-	1	3,8	4
	Total	7,12	15	-	46

7.5.7 Interpretation of the results

The local characterization factor for surface water tended to be smaller than that for groundwater. The contribution of groundwater use for wheat production increases from 57 % in water footprint inventory to 61 % in water scarcity footprint in location A, and then 7 % to 9 % in location B. As a result, the water scarcity footprint of 1 t of wheat production in location A has 40 times the value of that in location B. The pattern of water use for wheat production such as balance of intake source and water efficiency varies by nations. Additionally the potential impacts of water uses vary by place and source of water. This characterization concept enables objective weighting of water resources by location and source of water, and therefore facilitates practical and robust characterization of water use.

7.5.8 Strengths and weakness of the approach

The characterization result can be understood intuitively, because its units (m^3 H2Oe) are based on water volume (m^3). Since all characterization factors worldwide have the same reference condition, the characterization results can be summed up.

Editing note: Should we say “characterization result” or “characterized result”?

The method applied in this example can reflect the difference of water availability by water source, including surface water and groundwater, in addition to geographical location. Because of the simple framework to estimate local characterization factors, the seasonality of the characterization factors can also be reflected by setting reference conditions.

In this example, evapotranspiration from precipitation is excluded from the water footprint inventory analysis and water footprint impact assessment.

7.5.9 Bibliography

[1] Monfreda C., Ramankutty N., and Foley J.A. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Glob. Biogeochem. Cycles*, 22, 2008, GB1022

[2] Siebert S., Doll P., Hoogeveen J., Faures J. M., Frenken K., and Feick S. Development and validation of the global map of irrigation areas. *Hydrol. and Earth Syst. Sci.,* 9, 2005, pp. 535-547

[3] Yano S, Hanasaki N, Itsubo N, Oki T Characterization factors for water availability footprint considering the difference of water sources based on a global water resource model. *J. LCA Jpn.*, 10, 2014, pp. 327-339

[4] Yano S. Assessment of Environmental Impacts on Freshwater Availability and Sustainability of Human Activities. PhD thesis, The University of Tokyo, 2015, pp. 1-172

[5] Hanasaki N, Inuzuka T, Kanae S, Oki T. An estimation of global virtual water flow and sources of water withdrawal for major crops and livestock products using a global hydrological model. *J. Hydrol.*, 384, 2010, pp. 232-244

[6] Hanasaki N, Kanae S, Oki T, Masuda K, Motoya K, Shirakawa N, Shen Y, Tanaka K. An integrated model for the assessment of global water resources – Part 1: Model description and input meteorological forcing. *Hydrol. and Earth Syst. Sci.*, 12, 2008, pp. 1007-1025

[7] Weedon GP, Gomes S, Viterbo P, Shuttleworth WJ, Blyth E, Österle H, Adam JC, Bellouin N, Boucher O, Best M. Creation of the WATCH Forcing Data and Its Use to Assess Global and Regional Reference Crop Evaporation over Land during the Twentieth Century. *J. Hydrometeor.*, 12, 2001, pp. 823–848

7.6 Example G – Variation of water scarcity footprint by forest management and land use change

Editing note: This was example B2 in WD3

7.6.1 Introduction

This example intends to show an example of variation of characterization factors and water scarcity footprint by forest management and land use change related to human activities.

System boundary is determined for change of characterization factors for different water sources by forest management and land use change. Geographical coverage is determined for three locations; location C in a natural watershed without thinning, location D in a natural watershed with appropriate thinning, and location E in an urban watershed. Other elements are same as Example B.

7.6.2 Water footprint inventory analysis

7.6.2.1 Water footprint inventory calculation

As the water footprint inventory result, the value for wheat production at location A in Example B is adopted.

7.6.2.2 Characterization

The local characterization factors of a process at a specific surface condition are determined as shown in Tableau 12, Tableau 13 and Tableau 14:

Tableau 12 - Local characterization factors for natural watersheds without thinning

	Annual rate of hydrological cycle (mm/year)	Required area - A_{Sw}, A_{Gw} (m^2)	Required area, reference - A_{ref} (m^2)	Local characterization factor (m^2/m^2)
Surface water	600	1.7	1	1.7

Groundwater	500	2.0	1	2.0

Tableau 13 - Local characterization factors for natural watersheds with appropriate thinning

	Annual rate of hydrological cycle (mm/year)	Required area - A_{Sw}, A_{Gw} (m^2)	Required area, reference - A_{ref} (m^2)	Local characterization factor (m^2/m^2)
Surface water	670	1.5	1	1.5
Groundwater	558	1.8	1	1.8

Tableau 14 - Local characterization factors for urban watersheds

	Annual rate of hydrological cycle (mm/year)	Required area - A_{Sw}, A_{Gw} (m^2)	Required area, reference - A_{ref} (m^2)	Local characterization factor (m^2/m^2)
Surface water	720	1.4	1	1.4
Groundwater	170	5.9	1	5.9

The data on annual rate of hydrological cycle of natural watersheds and urban watersheds are based on [1]. The data on annual rate of hydrological cycle of natural watersheds with appropriate thinning are based on [2]

7.6.2.3 Water scarcity footprint

The water scarcity footprint is calculated from the water use figures and the local characterization factors, by summing up three different characterization results, as shown in Tableau 15, Tableau 16, and Tableau 17:

Tableau 15 - Calculation of the water scarcity footprint of the process in natural watersheds without thinning

	Water footprint inventory (m^3/year)	Local characterization factor (m^2/m^2)	Water scarcity footprint (m^3 H_2Oe / year)
Surface water	111	1.7	189
Groundwater	149	2.0	298
Total	260		487

Tableau 16 - Calculation of the water scarcity footprint of the process in natural watersheds with appropriate thinning

	Water footprint inventory (m^3/year)	Local characterization factor (m^2/m^2)	Water scarcity footprint (m^3 H_2Oe / year)
Surface water	111	1.5	167
Groundwater	149	1.8	268
Total	260		435

Tableau 17 - Calculation of the water scarcity footprint of the process in urban watersheds

	Water footprint inventory (m^3/year)	Local characterization factor (m^2/m^2)	Water scarcity footprint (m^3 H_2Oe / year)
Surface water	111	1.4	155
Groundwater	149	5.9	879
Total	260		1034

7.6.3 Interpretation of the results

The method applied in this example can reflect the difference of water scarcity between natural watersheds containing forests and urban watersheds. The method can also be applied for evaluating the effect of forest management (e.g. thinning) in terms of water scarcity.

7.6.4 Bibliography

[1] Ando Y, Mushiake K, Takahashi Y. Hydrological Cycle in a Small Experimental Basin Equipped in a Hilly Land, Annual Journal of Hydraulic Engineering, 25, 1981, pp. 197-208 (in Japanese).

[2] Kubota T, Noguchi S, Tsuboyama Y, Nobuhiro T, Kaneko T, Iwayama A. http://www.ffpri.affrc.go.jp/pubs/seikasenshu/2013/documents/p38-39.pdf, 2013 (in Japanese).

8 Examples of a water footprint that can be either assessed as a single impact category or as a (non-comprehensive) profile

8.1 Example H - Water eutrophication footprint calculated as one or two indicators

Editing note: This is example E in WD3.

8.1.1 Goal and scope

This example shows how to assess the water eutrophication footprint of maize production in a fictive region X (let say for example the region of Winterfell).

8.1.2 Life cycle inventory

Tableau 18 summarizes elementary flows contributing to water eutrophication assessed through a life cycle inventory analysis using both collected data and data gathered using background databases[2].

Tableau 18 — Elementary flows contributing to water eutrophication

Substance	Emission to	Amount emitted (kg/t of maize)		
		Upstream (e.g. from input materials)	Direct emissions (e.g. during cultivation)	Total
Ammonia	Air	0,084	1,096	1,180
Nitrogen oxides	Air	0,718	0,298	1,016
COD	Water	0,610	0,000	0,610
Nitrate	Water	3,107	23,909	27,016
Phosphorus	Water	0,002	0,105	0,107

8.1.3 Impact assessment

8.1.3.1 Characterization factors

A method Y is selected to assess water eutrophication. This method Y assesses separately impacts from eutrophication for P-limited and N-limited watersheds. As a sensitivity analysis, a method Z is selected to assess water eutrophication. This method Z assessed impacts from water eutrophication considering both P-based and N-based substances in a single impact category. The characterization factors for calculating water eutrophication potential from those two methods are presented in Tableau 19.

Tableau 19 — Characterization factors for water eutrophication

Substance (and compartment of emission)	Water eutrophication potential		
	Impact assessment method Y		Impact assessment method Z
	P-limited watersheds (expressed in kg P eq/kg)	N-limited watersheds (expressed in kg N eq/kg)	Undefined watershed (expressed in kg PO_4^{3-} eq/kg)
Ammonia, to air	0	0,092	0,175

[2] Fictive values for the sake of the example. Do not reuse.

Nitrogen oxides, to air	0	Not provided (characterization factor of Nitrogen dioxides, to air, of 0.389 is used as a proxy)	0,065
COD, to water	Not provided	Not provided	0,022
Nitrate, to water	0	0.226	0,05
Phosphorus, to water	1	0	1,53

8.1.3.2 Water eutrophication footprint calculation

Tableau 20 presents the calculation of the water eutrophication footprint. It is simply the amount of substance emitted into the environment multiplied by its respective characterization factor.

Tableau 20 — Calculation of the water eutrophication footprint for both impact assessment method Y and method Z

Substance (and compartment of emission)	Amount emitted (kg/t of maize)	Water eutrophication potential		
		Impact assessment method Y		Impact assessment method Z
		P-limited watersheds (expressed in kg P eq/kg)	N-limited watersheds (expressed in kg N eq/kg)	Undefined watershed (expressed in kg PO_4^{3-} eq/kg)
Ammonia, to air	1,180	0	0,109	0,207
Nitrogen oxides, to air	1,016	0	0,395	0,066
COD, to water	0,610	n/a	n/a	0,013
Nitrate, to water	27,016	0	6,106	1,351
Phosphorus, to water	0,107	0,107	0	0,164
Total		**0,107**	**6,609**	**1,800**

As the final result, the water eutrophication footprint, expressed in kg of a reference substance equivalent (a typical midpoint unit), caused by the production of one tonne of maize is assessed to be:

- 0,107 kg P eq and 6,609 kg N eq for P-limited watersheds and N-limited watersheds respectively, by the impact assessment method Y, and
- 1,800 kg PO_4^{3-} eq by the impact assessment method Z.

8.1.3.3 Interpretation and learning

This example shows that emissions emitted to other compartment than water (in this case to air) can also contribute to water degradation footprint.

This example also shows that different impact assessment methods assess an impact differently (in that case method Y assesses water eutrophication footprint as a profile of two impact categories whereas method Z assesses water eutrophication as a single indicator).

This example also shows that different impact assessment methods can have a different coverage of substances. For example, in this example the impact assessment method Y does not provide characterization factors for COD. This can be either due to the fact that this impact assessment method explicitly considered COD as not being a cause of water eutrophication or because the characterization factor is simply missing. This shows the importance to understand if some substances are not characterized by a method and if so why. In case this comes from a missing characterization factor, it may be wise to either add this missing characterization factor, change impact assessment method or at least reflect it in the interpretation and limits of the study. Note that a characterization factor of 0 is not the same as a missing characterization factor: a characterization factor of 0 is an explicit statement that this substance is not considered to contribute to this impact category whereas a missing characterization factor does not give any information on why this substance is not characterized in that specific impact assessment method.

This example also shows that different units can be used to express the results of the same impact (in this example one finds the three different units “kg P eq”, “kg N eq” and “kg PO_4^{3-} eq” to express water eutrophication potential).

8.2 Example I – Partial water degradation footprint (looking only at emissions to water)

Editing note: This is example F in WD3.

8.2.1 Background

An LCA of a pigment production is used as the comprehensive LCA to which a (partial) water degradation footprint caused by emissions to water was added.

Carotenoids pigments are widely used as feed additives in the poultry sector and in salmonid and crustacean aquaculture. In these applications the egg, skin or flesh of the target species are pigmented in order to improve marketability.

The poultry feed producer is able to source these carotenoids (or indeed, xanthophylls) from either chemical synthesis, or from processed plant materials. Canthaxanthin, or paprika oleoresin (containing capsanthin and capsorubin), may be used to provide red colors to the egg-yolk. C30-ester, or marigold oleoresin (supplying lutein and zeaxanthin), both yield a yellow egg-yolk color.

A cradle-to-grave assessment, studying all aspects of the production chain, revealed that the products derived through synthetic chemistry had the least impact on the environment. The (partial) water degradation footprint caused by emissions to water was part of this assessment.

8.2.2 Selection of impact categories, category indicators and characterization models

This example proposes assessing the (partial) water degradation footprint based on different emissions to water: COD: chemical oxygen demand; N-total: total nitrogen; P-total: total phosphorus; AOX: adsorbable organic halides; Hg: mercury; Cd: cadmium; Zn: zinc; Cu: copper; Ni: nickel; Pb; lead; Sn: tin; SO42-: sulfate; Cl-: chloride.

The assessment of partial water degradation is carried out by means of a model named “critical water volume (CWV)”. For selected pollutants that enter the water, the theoretical water volume required to dilute the pollutant to the statutory limit value (critical load) is determined. The volumes calculated for each pollutant are added up to yield the partial water degradation footprint.

The factors for calculating the (partial) water degradation footprint. are shown in Tableau 21. The requirements that are made on sewage at the entry point into surface water, listed in the appendices to the German Waste Water Regulation (AbwV), are the basis for the factors.

These limit values are generally based on the relevance of the emitted substance for the environment; in some cases, technical issues were taken into account in establishing the regulation. The more critical a pollutant is due to its environmental effect in the aquatic system, the higher the relevant characterization factor is. Based on scientific criteria, the potential of different pollutants to harm the environment is assessed and expressed in the α_i-Factor. Tableau 21 shows the characterization factors. Hg for example has a much higher characterization factor than COD. The effect of the same mass of Hg is therefore much more critical to the environment than that of COD. To express that effects in numbers, the same amount of pollutants must be diluted with much more water in the case of Hg than for COD. The higher amount of the theoretical water volume for Hg to reach a defined threshold level expresses the more severe effects that this pollutant has compared to COD.

In spite of this restriction, this method is used for several reasons:

— existence of database for most of the emissions

— recognition of the Waste Water Regulation and

— broad acceptance of the associated limit values including regulation

The partial water degradation footprint is calculated with:

$$WF_{Deg} \quad \sum a_i \times E_i \qquad (1)$$

where

WF_{Deg} is the atrial water degradation footprint, expressed in L H_2Oe.

α_i is the characterization factor for each E_i which can be obtained for each pollutant (i).

E_i is the amount of pollutants emitted to water.

8.2.3 Results

In this case study, Cr emissions have the highest impact to the partial water degradation footprint (Tableau 21). The goal will be to reduce this specific pollutant to improve the environmental impacts.

The whole (partial) water degradation footprint is then expressed as the sum of the evaluation results of the different pollutants. The total result can be used to compare the performance of different alternatives fulfilling the same functional unit and to initiate improvement activities.

Tableau 21 — Overview of pollutants and their calculation factors for the critical water volumes (CWV)

Pollutants to water	E_i -Value (mg) from case study	Requirement on waste water (mg/l Appendix Nr 22 to German Waste water regulation (AbwV)	α_i -Factors for calculating the CWV (L H_2Oe) / mg)	Result (L H_2Oe)
COD [a]	4045	75	1/75	53,9
N total	249	13	1/13	3,3
P total	29	2	1/2	14,5
AOX [a]	0,202	1	1	0,2
Hg	0,28	0,001	1000	280,0
Cd	0,078	0,005	200	15,5
Cr	33	0,05	20	666,1
Zn	68	0,2	5	342,3
Cu	23	0,1	10	230,0
Ni	12	0,05	20	240,0
Pb	3	0,05	20	60,0
Sn	4	0,2	5	20,0
Sulphate	2462	10 000	1/10000	0,2
Chloride	12060	10 000	1/10000	1,2
			Partial water degradation footprint (L H_2Oe)	1927,3

[a] COD is chemical oxygen demand and AOX is the abbreviation of the sum parameter for water soluble "adsorbable organic halogens" in which 'A' stands for adsorbable, 'O' for organic and 'X' for the halogens chlorine, bromine and iodine, see 2.2.

The needed LCI data can be generated with specific inputs derived from water measurements methods of OECD. With these methods data from production processes can be used and transferred to the indicator results. Furthermore, the relevant data can be extracted from LCI of commonly used databases for LCA.

8.2.4 Similar approach: The partial water degradation footprint for pollutants to water as calculated by the method of the grey water footprint from the Water footprint Network

The concept of the grey water footprint from the Water Footprint Network is the partial water degradation footprint calculated as follows:

$$WF_{Deg} \quad \sum \frac{L}{c_{max} \quad c_{nat}} \qquad (2)$$

where

WF_{Deg} is the partial water degradation footprint, expressed in L H_2Oe per functional unit.

L is the load of the pollutant (mg / functional unit). It is calculated by multiplying the effluent discharge rate (L H_2O / time unit) with the pollutant concentration of the effluent (in mg / L H_2O x functional unit)

c_{max} is the maximum acceptable concentration of the pollutant (in mg / L H_2Oe)

c_{nat} is the natural background concentration of the pollutant in the receiving water body (in mg / L H_2Oe).

In the case of several pollutants, the partial water degradation footprint is calculated for each of the pollutants and the highest of the resulting values is selected.

Both concepts presented in this example are partial water degradation footprints as they only take into account pollutants emitted directly to water and not considering pollutants emitted to air that will go to water and only partially pollutants emitted to soil that will reach water.

8.2.5 Final note

The environmental relevance of the water scarcity footprint can vary depending on the water use and the local water resources situations and may have a lower environmental relevance, compared with the water degradation footprint.

8.2.6 Bibliography

[1] Saling, P.; Kicherer, A.; Dittrich-Kraemer, B.; Wittlinger, R.; Zombik, W; Schmidt, I.; Schrott, W.; Schmidt, S., Eco-efficiency analysis by BASF – The method, Int J. LCA 7 (4), 2002, 203-218.

[2] Baker, R. and Saling P., Comparing natural with chemical additive production, Feed Mix, 11, 1, 2003,12-14.

[3] Saling, P., Baker, R., Gensch, C.-O., Quack, D, Differences in Life-Cycle Assessment for the Production of Various Carotenoid Additives for use in Poultry Feeds, Journal of Sustainable Agriculture, 29 (1), 2006, 15-41.

[4] Hoekstra A., Chapagain A., Aldaya M., Merkonnen M.; The Water Footprint Assessment Manual: setting the global standard. Earthscan, London, UK, 2011

9 Examples of water footprint profiles

9.1 Example J – Water footprint (comprehensive profile)

Editing note: This is example G in WD3.

This example is for illustrative purposes of method application. It shows a “water footprint”, being a comprehensive water footprint profile, presented at the midpoint and endpoint levels, and representing all relevant impacts related to water. According to the standard ISO 14046, this option can be referred to as a water footprint.

9.1.1 Description of the case – production of a packaging material

This fictive example is a cradle-to-gate example of 1 t of a specific packaging material in a location X.

9.1.2 Water footprint inventory

The water footprint inventory is calculated as the sum of foreground and background water footprint inventory. The foreground water footprint inventory is based on primary data collected at the production site for direct water withdrawal and release, direct emissions to air, soil and water as well as direct activity data of the site (i.e. amount of electricity consumed, amount of fuel consumed, amount of material input, etc.) per t of packaging material produced. The background water footprint inventory (i.e. the water footprint inventory associated with electricity, energy and material purchased by the factory as well as for the treatment of waste exported from the factory) is calculated using a background inventory database (for example using ecoinvent [1]).

Let’s assume that once the water footprint inventory analysis is done, it gives a dataset equal to the process “Paper, woodcontaining, lightweight coated (RER)” from “Allocation, recycled content” of ecoinvent version 3.2 [1].

9.1.3 Water footprint

With a comprehensive assessment expressed as a water footprint profile, using existing models, all water-related impacts can be captured. This can either be done:

- manually, by calculating each of the indicator results below (or by justifying the ones to leave out), or by
- using LCA tools, which integrate available methods, and can be used within available softwares and using current databases.

For the purpose of this example, the dataset obtained in the water footprint inventory analysis is characterized for each impact categories presented in Tableau 22 with the respective characterization models presented in Tableau 22.

The resulting indicators are shown in Tableau 22 (Water footprint profile, showing all impact categories, expressed at midpoint and at endpoint) or in Tableau 23 (Water footprint profile, at the level of the area of protection, express at endpoint). All three presentations can be referred to as Water footprint.

Tableau 22 — Water footprint profile expressed at the level of impact categories, expressed at the level of midpoint and endpoint respectively (for 1 t of a specific packaging material)

Type of impact	Impact category	Assessment at midpoint			Assessment at endpoint		
		Impact indicator results	Units	Method	Impact indicator results	Units	Method
Water degradation footprint	Freshwater ecotoxicity	14'300	CTUe	USEtox [2]	7.8	PDF.m^2.a	Using 5.48E-4 PDF.m^2.a/CTUe
	Marine ecotoxicity	2.11E+6	Kg 1,4-DB eq	CML baseline v3.02 [3]	5.17E+6	PDF.m^2.a	Using freshwater ecotoxicity of 1,4-DB of IMPACT 2002+ [4] as a proxy (2.45 PDF.m^2.a/kg 1,4-DB) Note: therefore to be taken with care
	Freshwater acidification	12	Mol H+ eq	PEF/OEF [5]	0.08	PDF.m^2.a	Using 6.73E-3 PDF.m^2.a/mol H+ eq
	Marine acidification	1700	Kg CO_2	Only CO_2 emissions are considered in this impact category	284	PDF.m^2.a	IMPACT World+ [6]
	Freshwater eutrophication	0.876	kg P eq	PEF/OEF [5]	14.6	PDF.m^2.a	IMPACT World+ [6]
	Marine eutrophication	1.98	kg N eq	PEF/OEF [5]	3.01	PDF.m^2.a	IMPACT World+ [6]
	Ionizing radiation (impact on freshwater ecosystem)	0.0011	CTUe	USEtox [2]	6E-7	PDF.m^2.a	Using 5.48E-4 PDF.m^2.a/CTUe
	Ionizing radiation (impact on marine water ecosystem)	n/a	CTUe	n/a	n/a	PDF.m^2.a	n/a
	Thermally polluted water	0.00198	PDF.m^2.a	Verones et al. [7]	0.00198	PDF.m^2.a	Verones et al. [7] as implemented in IMPACT World+ [6]
	Human toxicity carcinogens	9.49E-5	CTUh,c	USEtox [2]	0.0012	DALY	USEtox [2], converted to DALY considering 13 DALY/case$_c$ [4]
	Human toxicity Non-carcinogens	0.00089	CTUh,n-c	USEtox [2]	0.0012	DALY	USEtox [2], converted to DALY considering 1.3 DALY/case$_{n-c}$ [4]
	Ionizing radiation (impact on human health)	588	kBq U235 eq	PEF/OEF [5]	1.23E-5	DALY	IMPACT World+ [6]
Water scarcity footprint (different alternatives)	Water scarcity footprint	4.03	m^3 H2Oe	Frischknecht [8]	n/a	DALY	n/a
					n/a	PDF.m^2.a	n/a
	Water scarcity footprint	30.3	m^3 H2Oe	Hoekstra [9]	n/a	DALY	n/a
					n/a	PDF.m^2.a	n/a
	Water scarcity footprint	16.6	m^3 H2Oe	Berger [10]	n/a	DALY	n/a
					n/a	PDF.m^2.a	n/a

	Water scarcity footprint	14.8	m^3 H2Oe	Pfister et al. [11]	1.27E-5	DALY	Pfister et al. [11]
					13	PDF.m^2.a	Pfister et al. [11]
	Water scarcity footprint	17.5	m^3 H2Oe	Boulay et al. [12]	-0.3	DALY	Boulay et al. [12] as implemented in IMPACT World+ [6]
					0.001	PDF.m^2.a	Hannafiah et al. [13] as implemented in IMPACT World+ [6]
	Water scarcity footprint	n/a	m^3 H2Oe	Motoshita et al. [14]	0.013	DALY	Motoshita et al. [14]
					n/a	PDF.m^2.a	Motoshita et al. [14]
Water use	Reduction of shallow ground water	1.6	m^3 pumped	Simple inventory	0.32	PDF.m^2.a	Ven Zelm [15] (0.2 PDF.m^2.a/m3 shallow ground water)
	Change in water stream from Hydropower	7'700	m^3 turbined	Simple inventory	31	PDF.m^2.a	0.004 PDF.m^2.a/m3 turbined [16]

Expressing the results in endpoint units allows assessing which impact category is contributing more to the impact on each area of protection.

If deemed necessary, the water footprint profile can be expressed grouping all impact categories contributing to impact on the area of protection human health and those contributing to impact on the area of protection ecosystem (as shown in Tableau 23).

Tableau 23 — Water footprint profile expressed at the level of area of protection (and using endpoint units)

Type of impact	Area of protection	Impact indicator results	Units	Method
Water degradation footprint	Ecosystems	310 (up to 5E+6 if Marine water ecotoxicity is considered*)	PDF.m^2.a	Sum of Freshwater ecotoxicity, Freshwater acidification, Marine acidification, Freshwater eutrophication, Marine eutrophication, Ionizing radiation (impact on freshwater ecosystems), Thermally polluted water, as well as Marine water ecotoxicity if considered robust Note : missing characterized impact category is Marine water impact from ionizing radiation
	Human health	0.024	DALY	Sum of Human toxicity (carcinogens), Human toxicity (non-carcinogens) and Impact on human health from Ionizing radiation
Water scarcity footprint	Human health	Between -0.3 and 0.013	DALY	Water deprivation for human users (variation of different methods shown here)
	Ecosystems	Between 0.001 and 13	PDF.m^2.a	Water use impacts on ecosystem (variation of different methods shown here)
Water use	Ecosystems	31.32	PDF.m^2.a	Sum of Reduction of shallow groundwater, Water stream management

*NOTE: but to be considered with care as CML may be overestimated for marine ecotox and the conversion factor is based on freshwater ecotox: but the information is that more research is needed in this area as marine ecotox may be the dominant issue for water degradation footprint.

Note: whatever the approach used (i.e. midpoint or endpoint), the impact categories related to human toxicity (cancer, non-cancer, and from ionizing radiations) should only account for emissions reaching humans through either water emission or through air and soil emissions going to water and being ingested by humans through water consumption or fish consumption. In practice, models may not always be able to do so. In the present example, the complete impacts on human health from those three impact categories is account for and is therefore an overestimation of the impacts on human health from water degradation footprint.

9.1.4 Bibliography

[1] Ecoinvent (2015). http://www.ecoinvent.org/

[2] Rosenbaum R, T. Bachmann, L. Gold, M. Huijbregts, O. Jolliet, R. Juraske, A. Koehler, H. Larsen, M. MacLeod, M. Margni, T. McKone, J. Payet, M. Schuhmacher, D. van de Meent, and M. Hauschild, “USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment,” The International Journal of Life Cycle Assessment, vol. 13, no. 7, pp. 532–546, 2008

[3] Guinee, J.B., Marieke Gorree, Reinout Heijungs, Gjalt Huppes, Rene Kleijn, Lauran van Oers, A. Wegener Sleeswijk, S. Suh, H.A. Udo de Haes, H. de Bruijn, R. van Duin, M.A.J. Huijbregts (2001). Handbook on Life Cycle Assessment, Operational guide to the ISO standards Volume 1, 2a, 2b and 3. http://cml.leiden.edu/software/data-cmlia.html

[4] Jolliet O, Margni M, Charles R, Humbert Sb, Payet Jr, Rebitzer G, Rosenbaum R (2003) IMPACT 2002+: A New Life Cycle Impact Assessment Methodology. Int J Life Cycle Assess 8 (6):324-330.

[5] European Commission. (2013). 2013/179/EU: Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. Annex II: Product Environmental Footprint (OEF) Guide. Annex III: Organisation Environmental Footprint (OEF) Guide. Official Journal of the European Union, L 124, Volume 56, May 4th, 2013.

[6] IMPACT World+ (2015). http://www.impactworldplus.org/en/.

[7] Verones F, M. M. Hanafiah, S. Pfister, M. A. J. Huijbregts, G. J. Pelletier, and A. Koehler, “Characterization factors for thermal pollution in freshwater aquatic environments,” Environ. Sci. Technol., vol. 45, no. 17, p. 7608, 2011

[8] Frischknecht R., Steiner R. and Jungbluth N. (2008): The Ecological Scarcity Method – Eco-Factors 2006. A method for impact assessment in LCA. Environmental studies no. 0906. Federal Office for the Environment (FOEN), Bern. 188 pp. (as implemented in PEF/OEF). Water stress indexes available on a google earth layer.

[9] Hoekstra AY and Mekonnen MM (2011). Global water scarcity: the monthly blue water footprint compared to blue water availability for the world’s major river basins. Value of water research report series No 53. September 2011. UNESCO-IHE Institute for Water Education, P.O. Box 3015 , 2601 DA Delft, The Netherlands.

[10] Berger M, van der Ent R, Eisner S, Bach V, and Finkbeiner M (2014). Water Accounting and Vulnerability Evaluation (WAVE): Considering Atmospheric Evaporation Recycling and the Risk of Freshwater Depletion in Water Footprinting. Environ. Sci. Technol. 48, 4521−4528. Water stress indexes available on a google earth layer.

[11] Pfister S, Koehler A, Hellweg S (2009) Assessing the environmental impact of freshwater consumption in LCA. Environ Sci Technol (43):4098-4104

[12] Boulay, A.-M.; Bulle, C.; Bayart, J.-B.; Deschenes, L.; Margni, M. Regional Characterization of Freshwater Use in LCA: Modeling Direct Impacts on Human Health Environmental Science & Technology 2011, 45, 8948-8957. Water stress indexes available on a google earth layer at http://www.ciraig.org/fr/wateruseimpacts.php

[13] Hanafiah M, M. A. Xenopoulos, S. Pfister, R. S. E. W. Leuven, and M. A. J. Huijbregts, “Characterization Factors for Water Consumption and Greenhouse Gas Emissions Based on Freshwater Fish Species Extinction,” Environmental Science & Technology, vol. 45, no. 12, pp. 5272–5278, 2011

[14] Motoshita, M., Itsubo, N., Inaba, A. 2011. Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity. Int J LCA 16, 65-73.

[15] Van Zelm R, M. Rombouts, J. Snepvangers, and M. A. J. Huijbregts, “Desiccation due to groundwater extraction in The Netherlands in LCIA.” Warsaw, Poland, 2008

[16] Humbert S and R. Maendly, “Empirical characterization model and factors assessing aquatic biodiversity damages of hydropower water use,” International Journal of Life Cycle Assessment, vol. Submitted, 2009.

9.2 Example K - Water footprint profile including weighting

Editing note: This is example H in WD3.

9.2.1 Introduction

This illustrative example describes the calculation of a direct water footprint according to the method of Ridoutt and Pfister [1] which integrates consumptive and degradative water use into a single stand-alone indicator. The method uses weighting, is based on the RECIPE impact assessment methodology [2], and utilizes the local characterization factors for freshwater consumption reported by Pfister et al. [3].

9.2.2 Inventory

The example is of a cereal cropping system involving 2 x 10^3 m^3 per ha of freshwater consumed for irrigation (local water scarcity index 0.20), and emissions of 4 kg phosphorous per ha to freshwater. The crop yield is 4,5 t per ha. Water consumed in the production, supply and application of fertilizer, as well as other farming operations (e.g. cultivating, harvesting) are ignored in this simplified example.

9.2.3 Direct water footprint calculation

Following Ridoutt and Pfister [1], the indicator results for direct water scarcity footprint (WF_{Sc}) and direct water degradation footprint (WF_{Deg}) are calculated according to Equations 1 and 3, and expressed in the reference units H_2Oe, where 1 m^3 H_2Oe represents the burden on water systems from 1 m^3 of freshwater consumption at the global average water scarcity index [4].

$$WF_{Sc} \quad \sum_i \frac{C_{W,i} . CF_i}{m} \qquad (1)$$

where

WF_{Sc} is the (direct) water scarcity footprint in H_2Oe per unit of production,

m is the mass of production,

C_W is the (direct) water consumed by production at location *i*, and

CF_i is the relevant local water scarcity characterisation factor, calculated according to Equation 2.

$$CF_i \quad \frac{CF_{SC,L}}{CF_{SC,GLO}} \qquad (2)$$

where

CF_i is the characterisation factor used to calculate the water scarcity footprint,

$C_{SC,L}$ is the local water scarcity index, and

$C_{SC,GLO}$ is the global average water scarcity index.

and

$$WF_{Deg} \quad \frac{R_{EWPS}}{m.R_c} \qquad (3)$$

where

WF_{Deg} is the (direct) water degradation footprint expressed in m^3 H_2Oe per unit of production,

R_{EWPS} is the RECIPE points determined for emissions to water for the production system,

R_x is the global average RECIPE points attributable to 1 m^3 of water consumption (i.e. 1.86 x 10^{-3} RECIPE points per m^3), and

m is the mass of production.

The single value, stand-alone (direct) water footprint result is obtained by summing the indicator results for (direct) water scarcity footprint and (direct) water degradation footprint according to Equation 4.

$$WF = WF_{Sc} + WF_{Deg} \quad (4)$$

where

WF is the (direct) water footprint,

WF_{Sc} is the (direct) water scarcity footprint in H2Oe per unit of production, and

WF_{Deg} is the (direct) water degradation footprint expressed in H2Oe per unit of production.

Concerning the application of the RECIPE impact assessment method, the individual endpoint results are normalised with European factors and weighted using the Hierarchist cultural perspective. This implies an equal weighting given to areas of protection “human health” and “ecosystems”. This weighting procedure was chosen because it represents a moderate cultural perspective. It is important to note that the application of alternative weighting procedures could impact on the absolute results and potentially change the relative importance of water consumed and water degraded in their contribution to the water footprint. Further details of the method are described elsewhere [1].

For the simplified cereal cropping example described above, the direct water footprint profile is shown in Tableau 24.

Tableau 24 — Direct water footprint profile

Indicator	Indicator result	Unit	Calculation*
Direct water scarcity footprint	0.15	m^3 H2Oe/kg	2 x 10^3 m^3 * (0.2/0.6) / 4500 kg
Direct water degradation footprint ▪ Freshwater eutrophication ▪ Terrestrial ecotoxicity ▪ Freshwater ecotoxicity ▪ Marine ecotoxicity Total direct water degradation footprint	▪ 0.05 ▪ 0.25 ▪ 0.03 ▪ 0.00 0.33	m^3 H2Oe/kg	▪ 4.07 x 10^{-1} RECIPE PTS / 1.86 x 10^{-3} / 4500 kg ▪ 2.11 RECIPE PTS / 1.86 x 10^{-3} / 4500 kg ▪ 2.62 x 10^{-1} RECIPE PTS / 1.86 x 10^{-3} / 4500 kg ▪ 4.92 x 10^{-5} RECIPE PTS / 1.86 x 10^{-3} / 4500 kg ∑ RECIPE PTS / 1.86 x 10^{-3} / 4500 kg

* Based on RECIPE Version 1.07 - July 2012; http://www.lcia-recipe.net

Editing note: ReCiPe does not seem to have ecotoxicity associated with P emissions. To be clarified in India.

Following Equation 4, the direct water footprint, being the sum of indicator results for direct water scarcity footprint and direct water degradation footprint, is 0.48 m^3 H_2Oe per kg crop product (at farm gate) (i.e. 0.15 plus 0.33).

Note that in this simplified example, the water scarcity footprint and water degradation footprint associated with other farming inputs than irrigation water and P (e.g. diesel, electricity, seeds, pesticides, etc.), is not considered.

9.2.4 Bibliography

[1] Ridoutt, B.G. and Pfister, S. A new water footprint calculation method integrating consumptive and degradative water use into a single stand-alone indicator. *Int. J. Life Cycle Ass.*, 18(1), 2013, p. 204-207

[2] Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J. and van Zelm, R. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. 1st ed., 2009, Ruimte en Milieu, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, The Netherlands

[3] Pfister, S., Koehler, A. and Hellweg, S. Assessing the environmental impacts of freshwater consumption in LCA. *Environ. Sci. Technol.*, 43(11), 2009, pp. 4098-4104

[4] Ridoutt, B.G. and Pfister, S. A revised approach to water footprinting to make transparent the impacts of production and consumption on global freshwater scarcity. *Global Environ. Chang.*, 20(1), 2010, pp. 113-120

9.3 Example L - Water footprint assessment as part of a complete product life cycle assessment

Editing note: This is example L in WD3.

Editing note: Possibility to add a second product to show how a comparison could be performed as well as to go to endpoint and/or normalization?

9.3.1 Background

The example does not attempt to provide absolute values but rather to offer a way to apply this standard.

This example is an example of an LCA study of a specific packaging material that exist but where the water scarcity footprint indicator was missing. This example shows how the water scarcity footprint can be added in an already existing LCA where this indicator was missing.

The original LCA study included conventional impact categories such as eutrophication and acidification, together with other impact categories selected originally for the LCA study. The LCIA profile resulting from this study is shown in Tableau 25.

Tableau 25 — Impact indicator results for the LCA of a specific packaging material

Impact category (in the original LCA study)	**Units**	**Impact score** (per t of packaging material)
Climate change fossil	T Fossil fuel CO_2 eq.	1,0
Energy non-renewable	GJ	1,05
Eutrophication	T N equiv.	7,3 x 10^{-4}
Ecotoxicity	T 2,4-D equiv.	0,24
Acidification	T H^+ equiv.	5,7 x 10^{-4}

However, it does not include the impact category “water availability” or "water scarcity". Using the guidance of ISO 14046, this impact category is integrated into the LCIA profile of the original study in order to obtain a more comprehensive LCIA profile.

The functional unit is a tonne of final product.

9.3.2 Water scarcity footprint

For the determination of the water scarcity footprint the following relationship was used:

$$W_{SC} = CF_{\alpha} \cdot C_{W} \quad (21)$$

where

W_{SC} is the water scarcity footprint per functional unit,

CF_{α} is the characterization factor for the water scarcity of the location (between 0 and 1 in the specific approach used in this example), and

C_{W} is the water consumption per functional unit.

For the purposes of this example, the process to gather the inventory data of water consumption and the method used to evaluate the characterization factor are not shown. In this example we assume that the CF_{α} was identified as being 1 and that C_{W} was determined to be 113 m^3.

9.3.3 Summary of results

The results are summarized in Tableau 26.

Tableau 26 — Summary of results: water scarcity indicator as part of the original LCA

		Impact category	**Units**	**Impact score** (per t of packaging material)
LCA profile		Climate change fossil	T Fossil fuel CO_2 eq.	1,0
		Energy non-	GJ	1,05

		renewable		
	Water footprint profile, as part of an LCA (assuming that here eutrophication, ecotox and acidification only refers to water)	Eutrophication	T N eq.	7,3 x 10-4
		Ecotoxicity	T 2,4-D eq.	0,24
		Acidification	T H^+ eq.	5,7 x 10-4
		Water scarcity footprint	m^3-eq	113

9.3.4 Conclusions

The water footprint assessment as part of a comprehensive product LCA study illustrated in this example, allows for a sensible examination of the risks or impacts of water withdrawal for product manufacturing in its scarcity and other aspects, both present and future. This examination was done in the context of the product system of one published LCA study used as example. It completes, in a logical manner, the most classical LCA methodology that typically miss the water scarcity impact category.

This application shows, as in the LCA study used in this example, how to enhance an existing LCA study with a water scarcity impact category.

9.4 Example M – Partial water footprint (considering water scarcity footprint but only a partial water degradation footprint)

Editing note: This is example P in WD3.

9.4.1 Goal and Scope

The goal of this example is to show an example of a partial water footprint that accounts for water scarcity and a partial water degradation footprint.

The goal of the study is the performance of a water scarcity footprint of a particular textile product: a pair of jeans. The assessment analyzes four different textile products, originating from cotton, but differing in final characteristics. The main intention of the study is to add a practical experience of a water footprint inventory analysis and water scarcity footprint impact assessment of the agricultural production of a particular product.

The water footprint inventory analysis is calculated as the result of the addition of the elementary flows in the different production stages per product unit.

The water scarcity footprint of the agricultural phase is provided as the resulting indicator of the impact category water scarcity. The indicator is the result of the characterization of the inventory result by a local scarcity characterization factor.

The scope of the water footprint inventory analysis is the foreground system of the production of 4 cotton textiles in Spain. It is further detailed in the inventory analysis. The scope of the water scarcity footprint is the production of raw cotton in southern Spain, in the year 2005.

9.4.2 Live cycle inventory analysis

9.4.2.1 Elementary flows

The elementary flows included the evaporation of freshwater from water bodies (freshwater consumption) and the evaporation or transpiration of soil water by plants (soil water consumption). For each of the elementary flows, the location and time of consumption is taken into account.

In addition to this, an elementary flow has been defined as “freshwater pollution”.

9.4.2.2 Production stages

The study covers the water footprint of a textile product by accounting for the elementary flows in each production stage. 4 different cotton textiles were included: dark and light denim, uncoloured and coloured non-denim textiles. The most relevant production stages from a water resources perspective are the cotton production stage and the spinning and weaving phase. In this example, only the foreground system of textile production has been taken into account in the inventory phase. Figure 7 details the elementary flows included.

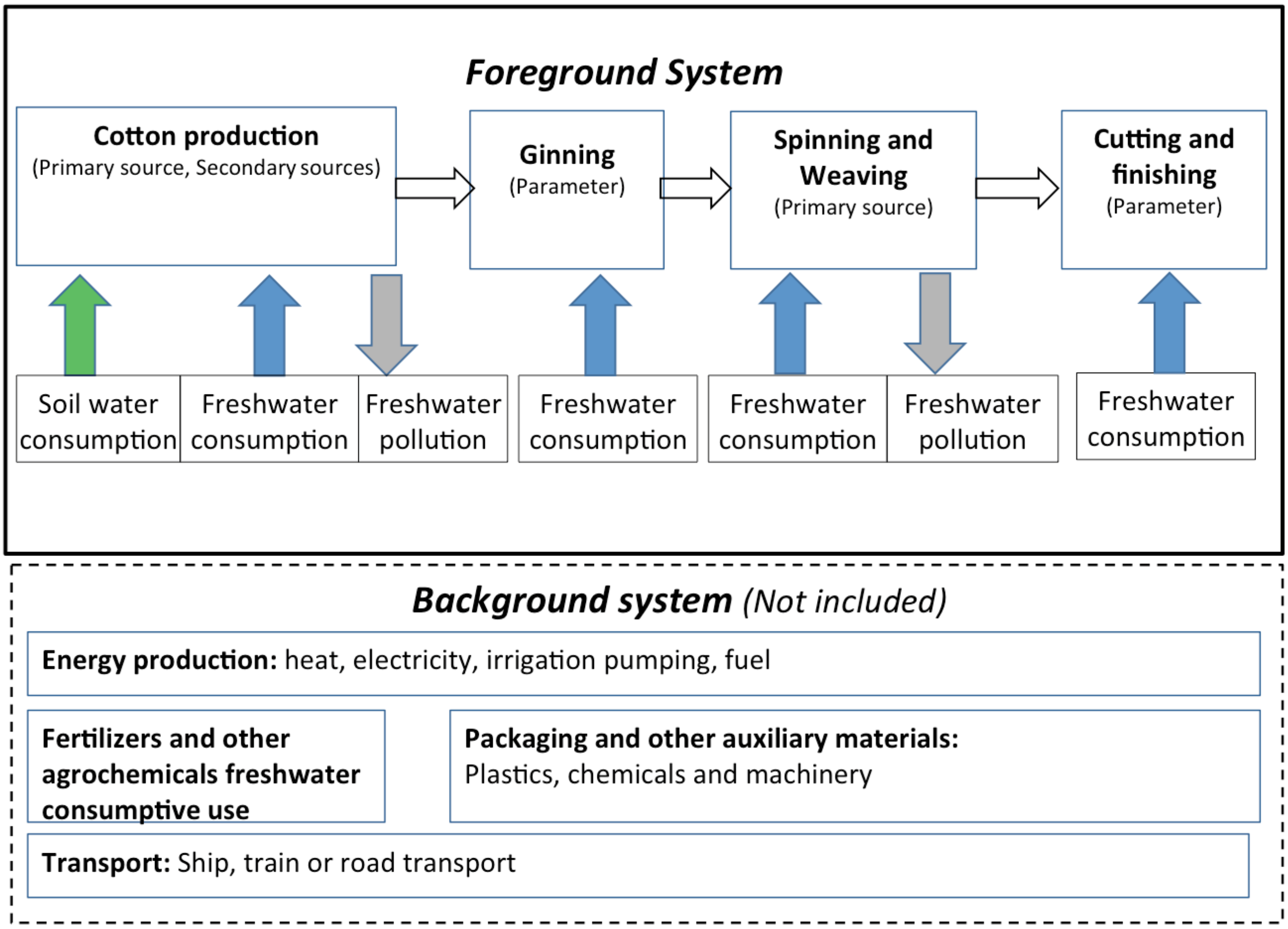


Figure 7 — Production stages in the fore- and background system and elementary flows included in the analysis

Editing note: Take off the “freshwater consumptive use” in the lower left box. Discuss how freshwater degradation (or pollution) should be presented.

The study estimated the elementary flows in the cotton production stage for typical crop system and conditions in the Guadalquivir, Guadalete and Barbate river basins, Southern Spain in the year 2005. The pollution in the cotton production stage was estimated based on the elementary flow of excess nitrogen fertilization.

Ginning freshwater consumption was estimated as the humidity needed for safe fibre storage. Freshwater consumption was measured in each sub process of the production chain, for each textile studied. The spinning, weaving, dyeing and finishing stages were integrated in a single production plant, and effluents where collected together before disposal to a municipal wastewater treatment plant. Therefore freshwater pollution was calculated together. It was based on the DQO parameter.

9.4.2.3 Inventory results

Tableau 27 presents the inventory results per production stage and textile. For clarity reasons, results for cotton production have been averaged between the two studied years and production methods, per cotton lint.

Tableau 27 — Inventory results for each inventory flow per production stage and textile

Textile	Cotton production (average values)			Ginning	Spinning	Weaving		Finishing
	Soil Water Consumption (l/kg lint)	Freshwater Consumption (l/kg lint)	Nitrogen (l/kg lint)	Freshwater Consumption (l/kg)	Freshwater Consumption (l/kg)	Freshwater Consumption (l/kg)	DQO (mg/kg)	Freshwater Consumption (l/kg)
Non denim uncoloured	175.5	1820.2	3.65	40.0	10.4	13.1	0.00006	90
Non denim - coloured	175.5	1820.2	3.65	40.0	10.4	33.9	0.00011	30
Denim Material light coloured	175.5	1820.2	3.65	40.0	32.8	15.3	0.00005	30
Denim Material Dark coloured	175.5	1820.2	3.65	40.0	39.5	15.3	0.0034	30

9.4.3 Life cycle inventory analysis

Tableau 28 presents the aggregation of the inventory results per textile product (one pair of jeans with a fiber density of 0.287 kg/m2 and 1.25 m2/product on average). Aggregation of the inventory results per production stage was done by using the concept of product fraction. In this case, since no waste reutilization has been taken into account, product fraction is the amount of product obtained from a primary material, in mass.

Tableau 28 — Life cycle inventory aggregated results per unit

Textile	Soil water consumption (kg/product)	Freshwater consumption (kg/product)	N (kg/product)	DQO (kg/product)
Non denim uncoloured	574.7	6151.9	4.96	7.83E-05
Non denim - coloured	574.7	6106.5	4.96	1.42E-04
Denim Material light coloured	574.7	6113.5	4.96	6.24E-04
Denim Material Dark coloured	574.7	6122.7	4.96	4.22E-03

9.4.4 Life cycle impact assessment

9.4.4.1 Water scarcity footprint

The impact category is agricultural water availability.

The characterization factor is the agricultural water scarcity index. The agricultural water scarcity index was calculated according to Chico et al. (2013) per river sub-basin and month as the ratio of total agricultural freshwater consumption to water available for agriculture. The estimation of the water available for agriculture has been estimated as the available water in dams, minus environmental flows and urban and industrial water needs, estimated with local data at sub-basin, monthly level.

The difference between stored water in river dams minus environmental flows, urban and industrial water needs would represent the agricultural available water. Tableau 29 presents the variables involved for the case of one river sub-basin.

Tableau 29 — Agricultural available water, sub-basin agricultural monthly freshwater consumption and agricultural water scarcity characterization factor in a river sub-basin

Sub-basin	month	Agricultural available water (Mm^3/month)	Sub-basin agricultural monthly freshwater consumption (Mm^3 H_2Oe/month)	Agricultural water scarcity characterization factor
Guadalete River	1	919.82	0.51	0.0006
Guadalete River	2	900.91	0.25	0.0003
Guadalete River	3	891.79	1.59	0.0018
Guadalete River	4	887.74	5.04	0.0057
Guadalete River	5	856.72	8.27	0.0097
Guadalete River	6	807.47	10.38	0.0129
Guadalete River	7	755.50	10.19	0.0135
Guadalete River	8	697.92	7.70	0.0111
Guadalete River	9	647.11	4.04	0.0063
Guadalete River	10	622.17	0.56	0.0009
Guadalete River	11	612.39	0.65	0.0011
Guadalete River	12	602.69	0.43	0.0007

Editing note: expressing freshwater consumption in H2Oe may need clarification.

Finally, Tableau 30 presents the results of the cotton water footprint inventory for the freshwater consumption and the resulting cotton agricultural water scarcity footprint in the presented sub-basin at a monthly level. The presented results represent the impact on agricultural water availability of cotton production in the area.

Tableau 30 — Agricultural water scarcity characterization factor, cotton production monthly freshwater consumption and cotton agricultural water scarcity footprint per month for the years 2005 and 2009 in the Guadalete river sub-basin

Sub-basin	month	Agricultural water scarcity characterization factor	Monthly freshwater consumption of cotton production (Mm^3 H2O-eq /month)	Cotton agricultural water scarcity footprint (Mm^3 H2O-eq /month)
Guadalete River	1	0.0006	0	0
Guadalete River	2	0.0003	0	0
Guadalete River	3	0.0018	0.56	0.001
Guadalete River	4	0.0057	2.91	0.017
Guadalete River	5	0.0097	4.64	0.045
Guadalete River	6	0.0129	6.69	0.086

Guadalete River	7	0.0135	6.91	0.093
Guadalete River	8	0.0111	5.80	0.064
Guadalete River	9	0.0063	3.23	0.020
Guadalete River	10	0.0009	0.45	0.000
Guadalete River	11	0.0011	0	0
Guadalete River	12	0.0007	0	0

9.4.4.2 Water degradation footprint

Water degradation is defined following Hoekstra et al. (2011) as the water volume needed for assimilating the load of pollutants given the ambient water quality standard in the receiving water body, calculated for each pollutant. This indicator is determined by the pollutant that is most critical, that is, the one that is associated with the largest pollutant-specific degradation.

Tableau 31 — Water degradation footprint results per production stage and textile (average values)

Textile	Cotton production (l/kg product)	Weaving (l/kg product)
	Freshwater degradation associated with Nitrogen	Freshwater degradation associated with DQO
Non denim uncoloured	442.9	0.08
Non denim - coloured	442.9	0.08
Denim Material light coloured	442.9	0.08
Denim Material Dark coloured	442.9	0.08

9.4.5 Interpretation of the results

The example presented a particular application of a water footprint inventory analysis and water scarcity footprint of a particular product. Thus, it shows the possibility of the methodology to be used in particular contexts with local data.

Results of the life cycle inventory analysis show the relative differences in the elementary flows of each production stage for the case of the production of a specific textile product.

The example of the water scarcity footprint of the agricultural stage presents the development of characterization factors with local data, and calculates a water scarcity footprint of cotton production. The example detailed the method used for the characterization factor, which could be reproduced in different locations. This allows a local analysis of the impact of cotton production freshwater consumption, signalling the places and months where this production poses greater impact over the water resource.

Its comparison with other water scarcity footprints which use a different characterization factor methodology should be carried out with caution.

9.4.6 Limitations

Editing note: Two alternatives are presented that discuss the limitations of this approach. A discussion is needed in India to find consensus. Inputs during the consultation are welcome.

9.4.6.1 Alternative 1

As a single indicator, the water degradation footprint does not have the capacity to account for all the different aspects that entails water quality degradation.

For instance, interactions between pollutants are only taken into account indirectly when they are reflected in the legal limit. Legal limits are used as a proxy for the environmental impact: this assumes that they are based and correlated to actual environmental impacts. This limitation is shared with all methods but modelling studies that study systems integrally.

Secondly, the grey water footprint does not consider the fate of pollutants in water systems, like decay processes and degradation downstream that lower concentrations

9.4.6.2 Alternative 2

The approach used in this example to assess the water degradation footprint uses a characterization model that has two specificities as compared to the more “traditional” life cycle assessment:

- It uses the legal limit as a proxy for the environmental impact: this assumes that the legal limits are based and correlated to actual environmental impacts (i.e. that the ratio between the legal limit of two pollutants is reflecting the ratio between the environmental impact of those two pollutants). This is not always the case as some legal limits may be influenced by other factors than purely the environmental impacts such as whether the BAT allows reaching them or simply by being influenced by lobbyists. This limitation has to be kept in mind when interpreting the results of this approach.

Editing note: The above paragraph may not be entirely correct as the grey water footprint uses "ambient water quality standards". This paragraph seems to refer to the "emission standards". Ambient-based standards establish restrictions on the concentration of a pollutant in a given environmental medium. Emission standards establish restrictions on emissions from a given plant or machine, sometimes according to the potential offered through the use of the best available technology. Reference: Markandya, A., Perelet, R, Mason, P. and Taylor, T. (2001) Dictionary of Environmental Economics. Earthscan. London.

- It uses only the “dominant” pollutants in the characterization model. It means that it assumes that the environmental impacts are correlated with the pollutant reaching first the legal limit, independently of the amount of other pollutants. It means, for example, that in a watershed where NO_3^- reaches first the legal limit as compared to PO_4^{3-} and glyphosate, a culture emitting 1 kg NO_3^-, 10 g PO_4^{3-} and 0.01 g of glyphosate, has the same impact as a culture emitting also 1 kg NO_3^- but only 2 g PO_4^{3-} and 0.001 g glyphosate. This assumption (i.e. that only the “dominant” substance “counts” for the environmental impact) is in contradiction with the more traditional life cycle impact assessment that accounts for cumulative impacts of different pollutants. Whether the approach presented in this example or the more traditional impact assessment is more correct is outside the scope of this Technical Report. However, the limitations associated with these assumptions have to be kept in mind when interpreting the results. Note that the approach using the P-limited and N-limited impact categories for water eutrophication is also based on the assumption that the impacts are linked to only the “dominant” pollutant: however, in that case both impact categories are presented together: this allows to not “loose” the “cumulative” view.

9.4.7 Bibliography

Chico, D., Aldaya, M.M. and Garrido, A. A water footprint assessment of a pair of jeans: the influence of agricultural policies on the sustainability of consumer products. Journal of Cleaner Production. 57, 2013, pp. 238–248.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. The water footprint assessment manual: Setting the global standard, Earthscan, London, UK, 2011.

9.5 Example N – Comprehensive profile and weighted water footprint (application to urban water cycle)

9.5.1 Introduction

This example aims to illustrate the different use of a comprehensive water footprint profile (at the level of both impact categories and areas of protection) compare to a single value water footprint (obtained after weighting). Also the use of a baseline for a product is illustrated here.

Description of the case – Urban water cycle

A water utility, located in a region A with relatively high water scarcity provides a service that integrates drinking water production and distribution to users and wastewater treatment before discharge into the environment.

9.5.2 Goal and scope

Assess the water footprint of urban water cycle as:

- a comprehensive water footprint profile, presented at the level impact categories and areas of protection, integrating all relevant impacts related to water.
- a single value obtained after weighting.

The functional unit is the distribution of one cubic meter of drinking water to users. This study includes direct water consumption and quality degradation generated through drinking water uses and also indirectly due to the consumption of energy and reagents at water and wastewater treatment plants. Elementary flows are the river water withdrawal (#1) and the treated wastewater discharge (#4) (Figure 8).

Note: For simplicity, other flows such as losses in the DW distribution network, the WW collection network and the Reuse water distribution network, are not taken into account in this example.

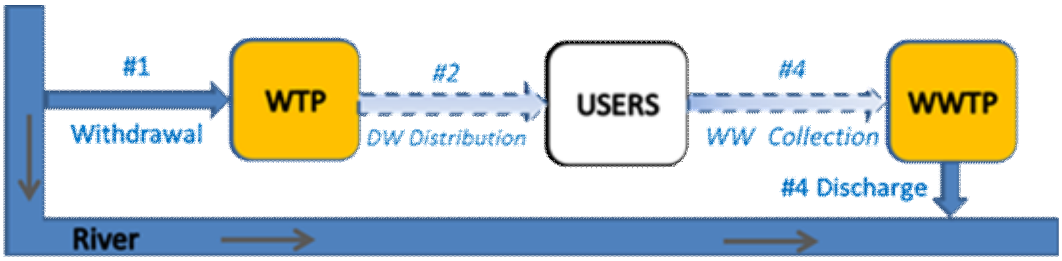


Figure 8 - Illustrative scheme of urban water cycle

9.5.3 Inventory analysis

Every day, 20'000 m^3 of drinking water are distributed. The wastewater generated by the use of this drinking water is sent to the WWTP for treatment previous its discharge into the river. The data of the water footprint inventory for water-related flows are presented in Tableau 32. Data, relevant for water footprint assessment, were also collected for all the reagents or energy used for water and wastewater treatment.

Tableau 32 - Collected data for the distribution of 1 m^3 of drinking water

	Description		Quantity	Unit
INPUT	River water withdrawal (#1)		1	m^3
OUTPOUT	Treated wastewater discharge (#4)		0,9	m^3
	Nitrogen	Ammonia	2	g

	Nitrogen	Nitrates	12	g
	Phosphorous	Phosphorous	2	g
	Hormones	Estradiol	$1x10^{-5}$	g
	Hormones	Ethinyl estradiol	$1x10^{-5}$	g
	Pesticides	Chloropyrifos	$5x10^{-5}$	g
	Pesticides	DCMU	$2,2x10^{-4}$	g
	PAHs	Anthracene	$2,2x10^{-4}$	g
	PAHS	Fluoranthene	$1x10^{-4}$	g
	Pharmaceuticals	Erythromycin	$1x10^{-4}$	g
	Pharmaceuticals	Ibuprofen	$3x10^{-4}$	g

PAHs: Polycyclic Aromatic Hydrocarbon.

Note: For simplicity, the inventory is limited to the most relevant parameters regarding water quality (selected micropollutants) or treatment plants life cycle (reagents, energy) but in practice it is recommended to be the more comprehensive as possible during water footprint assessment.

9.5.4 Impact assessment

9.5.4.1 Indicators

Indicators have been selected for different impact categories as well as the three area of protection and are summarized in Tableau 33.

Tableau 33 - Indicator and associated characterization model used

Type of indicators	Impact category	Characterisation model	Area of protection	Characterisation model
Consumptive water use	Water scarcity	Water scarcity index [1]	Ecosystems	Water deprivation effect to ecosystems [1]
			Human Health	Water deprivation effect to human health [1]
			Resources	Water deprivation effect to resources [1]
Water degradation	Freshwater eutrophication	ReCiPe [2]	Ecosystems	ReCiPe [2]
	Marine eutrophication	missing		missing
	Freshwater acidification	IMPACT 2002+ [3]		IMPACT 2002+ [3]
	Marine acidification	missing		missing
	Freshwater ecotoxicity	USEtox [4]		USEtox [4]
	Marine ecotoxicity	Missing		missing
	Toxicity to Human	USEtox [4]	Human Health	USEtox [4]

Note: In this example Impacts from ionizing radiation, thermal release as well as other types of water body use (such as groundwater extraction or hydropower use of stream) have not been included.

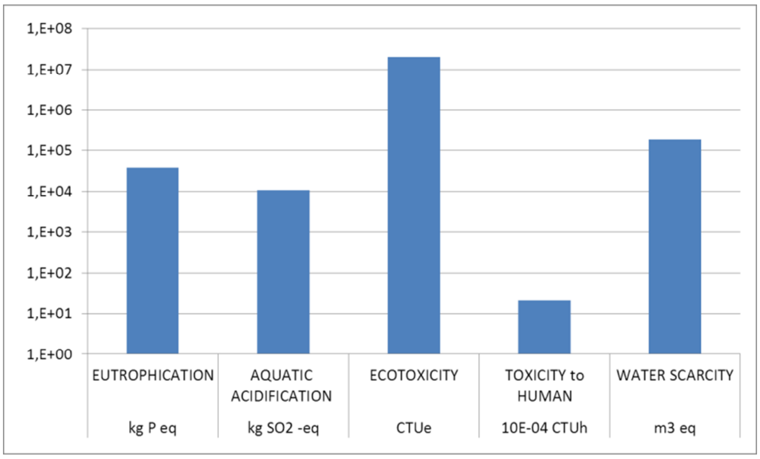
9.5.4.2 Weighing step

Based on the indicators assessed, a weighed water footprint is calculated according to an adaptation of the Ridoutt and Pfister method ([5] and [6]) which permits to aggregate impacts of both consumptive and degradative water use (CWU and DWU) into a single stand-alone indicator. The final result is expressed in litre of water equivalent (l H_2Oe), units more meaningful for public communication.

9.5.5 Interpretation

9.5.5.1 Baseline

Water footprint profiles are presented in Figure 9.



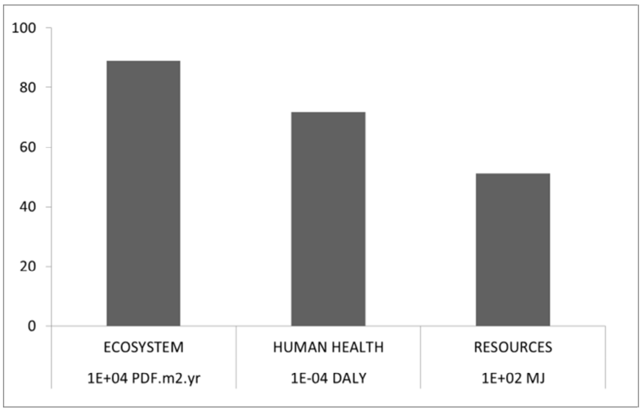


Figure 9 - Impact assessments results (at the level of impact categories (left, expressed in midpoint units) and area of protection (right, expressed in endpoint units))

The water scarcity footprint and water degradation footprint are calculated by aggregation and weighing, as presented before. Finally, the water footprint can be expressed single stand-alone indicator. In this example, water footprints are expressed in function of the functional unit, i.e. 1 m^3 of water distributed to users (Tableau 34).

Tableau 34 - Water scarcity footprint, water degradation footprint and and (weighed) water footprint of the baseline

	Water scarcity footprint	Water degradation footprint	(Weighted) water footprint
	l H_2Oe / m^3 water distributed to users		
Baseline	32	230	262

In this example, the water degradation footprint is more important than the water scarcity footprint. These results suggest that in order to reduce the global water footprint of this urban water cycle, improvement should be done on the discharge water quality.

9.5.5.2 Assessment of the water footprint after improvement of the service and comparison to the baseline.

In order to reduce the water degradation footprint, a tertiary treatment of the wastewater has been implemented at the wastewater treatment plant. It achieves better removal of nutrient and micropollutants whereas it increases the consumption of reagents and energy (Tableau 35).

Tableau 35 - Collected data for the distribution of 1 m^3 of drinking water after tertiary treatment implementation

	Description		Quantity	Unit
INPUT	River water withdrawal (#1)		1	m^3
OUTPOUT	Treated wastewater discharge (#4)		0,9	m^3
	Nitrogen	Ammonia	0,5	g
	Nitrogen	Nitrates	2	g
	Phosphorous	Phosphorous	0,5	g
	Micropollutants		Not detected	

After wastewater treatment improvement, both water degradation footprint and the global water footprint are reduced by 73 and 64%, respectively (Tableau 36). Based on these results, this example illustrates the interest to determine an initial baseline to evaluate the impact of process modifications on water footprint.

Tableau 36 - Weighed water footprint and degradative and scarcity water footprints after WWTP improvement and comparison to the baseline.

	Water scarcity footprint	Water degradation footprint	(Weighted) water footprint
	l H_2Oe / m^3 water distributed to users		
After improvement	32	61	93
Compared to the baseline	No variation	- 169 (-73%)	- 169 (- 64%)

9.5.6 Strengths and weaknesses of the approach chosen in that example

9.5.6.1 Strength

This example illustrates the interest of using several levels of water footprint indicators for partial and global water footprint. It permits to prioritize the actions for water footprint reduction. After modifications, the comparison to the baseline allows to follow the impacts on the partial and global water footprint.

9.5.6.2 Weakness

The approach could be improved by using (i) a comprehensive list of impact categories to ass the water degradation footprint, and (ii) monthly scarcity characterization factor. It also reflects overall performances based on annual values, but could be applied at daily level to take into account possible variation on water quality.

9.5.7 References

[1] Pfister, S., Koehler, A. and Hellweg, S. Assessing the environmental impact of freshwater consumption in LCA. *Environ. Sci. Technol.* 43, 2009, pp. 4098-4104.

[2] Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J. and van Zelm, R. ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level – First ed., 2009.

[3] Jolliet, O., Margni, M., Charles, R., Humbert, S., Payet, J., Rebitzer, G., Rosenbaum, R. IMPACT 2002+: A New Life Cycle Impact Assessment Methodology. *Int. J. Life Cycle Assess.* 8 (6), 2003, pp. 324-330.

[4] Rosenbaum, R., Bachmann, T., Gold, L., Huijbregts, M., Jolliet, O., Juraske, R., Koehler, A., Larsen, H., MacLeod, M., Margni, M., McKone, T., Payet, J., Schuhmacher, M., van de Meent, D., and Hauschild, M. "USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. *Int. J. Life Cycle Assess.* 13 (7), 2008, pp. 532–546.

[5] Ridoutt, B.G. and Pfister, S. A new water footprint calculation method integrating consumptive and degradative water use into a single stand-alone indicator. *Int. J. Life Cycle Assess.* 18, 2013, pp. 204–207.

[6] Penru, Y., Antoniucci, D., Besnault, S., Torras Balada, O. and Chevauché, C. WATERLILY®, Water Footprint Calculation Tool: Application To Urban Water Cycle. EcoSTP congress, Verona, Italy, 23-27 June 2014.

10 Examples of water footprint of organization

Editing note:

- 3 examples: chemical production (with OEF), aluminium (with unspecified), hotel (with Berger? / OEF)
- 1 gate to gate: chemical production
- 2 Cradle to gate: aluminium, hotel
- Organization with several sites (organizational boundaries) in location with different water scarcity, different suppliers (when cradle to gate at least electricity and a raw material)
- Add a section saying that this are examples of boundary but the boundary can be modified depending on the scope and standard with which the WF of Org. needs to comply.
- Impact assessment: water scarcity footprint and the relevant degradation footprint (if data are available)
- Do a calculation at least for the scarcity part
- Aggregation of results: show results per site and then aggregation
- Reporting unit: the overall activity of the organization during one year

10.1 Example O – Water scarcity footprint and partial water degradation footprint focusing on the sites of a company (example with a chemicals company)

10.1.1 Goal and scope definition

This is a fictitious example.

The goal of this example is to quantify the corporate sites water scarcity footprint and different types of corporate sites water degradation footprints of a chemicals producing company where the assessed activities of the facilities are owned by the chemical company. It will be outlined how the different corporate sites water footprints can be calculated. In the degradation section,

- a corporate sites eutrophication water degradation footprint,
- a corporate sites heavy metal water degradation footprint and
- a corporate sites organic substances water degradation footprint

were calculated and reported. In those examples, a chemicals company was chosen which operates many production sites worldwide and produces thousands of different products for different applications.

In this example, the organization has the financial and operative control over the facilities. It therefore accounts for the 100% of the potential environmental impacts related to water of their processes.

The reporting unit is the annual production of the company, produced on different sites. This example focuses on the gate-to-gate boundary. Later on, it might be possible to integrate upstream figures as well for all purchased products, if there are sufficient data available.

These are examples of boundary but the boundary can be modified depending on the scope and standard with which the water footprint of organization needs to comply.

10.1.2 Inventory analysis

The company collected from each of the facilities data on annual water inputs and outputs, in order to determine the direct water consumption. That includes cooling processes, electricity production, wastewater treatment facilities and waterworks which are owned and operated by the company.

The annual freshwater consumption from different sources includes the difference between the freshwater input and the freshwater discharge. Indirectly, the water content of the products are included if this water content was generated in the boundary of the reporting company. Products and their water content of upstream suppliers are not included.

The freshwater input is determined by quantifying the water which is supplied via water pipes by external suppliers, from site-owned groundwater sources or from rivers or lakes.

The freshwater discharge is determined as the volume of water which annually leaves the plant in sewage pipes minus the annual volume of storm water which flows through those pipes. Water evaporation from the area of the plant is not considered as it is assumed that the same volume of water had evaporated before the plant had been built.

Two sites have been considered more in details. The water use of those sites have been linked with the local water scarcity index $CF_{sc,i}$ via information based on Pfister et al [1]. Only those two sites can be summarized to an aggregated water footprint because averaging of freshwater consumption on the inventory level, as used for other LCI data, is not permitted for the determination of the water footprint (ISO 14046).

Additionally different water degradation footprints have been calculated by collecting data for emissions to water of heavy metals, nitrogen and organic substances expressed in COD. The worldwide operating database of the company collects data from every site and generates average figures. Though the geography may be relevant for the impact to the environment related to degradation, in practice, for the sake of simplification, aggregation is often done at the inventory level. It is considered, that no specific protection areas are linked with the emissions directly.

10.1.3 Impact assessment

10.1.3.1 Direct water scarcity footprint

The annual direct water scarcity footprint of a plant *n* is calculated as follows:

$$WF_{SC,n} = C_n \times \frac{CF_{SC,L}}{CF_{SC,Glo}} \quad (1)$$

where

$WF_{SC,n}$ is the direct water scarcity footprint of the plant *n*,

C_n is the annual direct freshwater consumption of this facility, i.e. the quantity of water which "disappears" by evaporation, integration into sold products or waste or direct release into the sea,

$CF_{SC,L}$ is the characterization factor to assess the water scarcity, being here the water scarcity index of the location where the facility operates

$CF_{SC,Glo}$ is the average global water scarcity index, i. e. 0,6

Editing note: Decide in India whether to keep or take off the last part about the average global water scarcity index.

The direct water scarcity footprint parameters of two sites with different water scarcity indices of the whole company are shown as an example in Tableau 37.

Tableau 37 - Corporate sites water scarcity footprint of the two sites belonging to the organization

Year 2013	Fresh water input	Total water discharge	Fresh water consumption	CF (water scarcity index of the region considered)	WSFP, total
	Mm^3	Mm^3	Mm^3		Mm^3 H_2Oe
Site 1, region 1	1.248	1.222	26	0,12	5,2
Site 2, region 2	232	227	5	0,13	1,0
Total	**1.480**	**1.449**	**31**		**6,2**

Most of the water is used for cooling of reactions and is discharged to the same water basin afterwards. A high amount of water is used several times for cooling before it is discharged back to the basin. Losses of water are linked to direct integration of water into products, losses by evaporation of electricity, steam production and in the condensation process of water after cooling in the different facilities of a site. The two sites of the evaluation produce their own electricity and steam on-site, so these water uses and losses are considered as well.

The water corporate sites scarcity water footprint of all facilities of the company form gate-to-gate is 6,2 Mm^3 H_2Oe. To generate a cradle-to-gate water corporate sites water scarcity footprint, all purchased products and all external services must be included. Therefor much more data will be needed from suppliers, in an ideal case for every single product that is purchased.

Editing note: Do we really want to call it "water corporate sites scarcity water footprint"?

10.1.3.2 Corporate sites partial water degradation footprint

During the production of chemicals, processes often use water directly in the processes for e.g. washing operations, quenching, reaction stopping, work-up, etc. This water contains after that uses often pollutants. In this example, only emissions to water were considered. Air or soil emissions from the sites with effect on water were not accounted for: therefore the water degradation footprint is only a partial assessment of water degradation.

The water is treated after its use in waste water treatment facilities and will be released to mainly the same water basin than it was withdrawn. The water has a good quality after the treatment, but there will be some remaining pollutants. This reduces the quality of water compared to fresh water and results in a water degradation footprint. The impact assessment can be done with different methods. In this example, the assessment of water degradation is carried out by means of the “critical water volume (CWV)” model [2]. For selected pollutants that enter the water, the theoretical water volume required to dilute the pollutant to the statutory limit value (critical load) is determined. The volumes calculated for each pollutant are added up to yield the water degradation footprint.

The factors for calculating the water degradation footprint are shown in the Tableau 38. The requirements that are made on sewage at the entry point into surface water, listed in the appendices to the German Waste Water Regulation (AbwV), are the basis for the factors. In general, region specific factors should be used for the different sites. Because they are not available for all regions, the factors of the German Waste Water Regulation (AbwV) can be used as default values.

These limit values are generally based on the relevance of the emitted substance for the environment; in some cases, technical issues were taken into account in establishing the regulation. The more critical a pollutant is due to its environmental effect in the aquatic system, the higher the -relevant characterization factor is. Based on scientific criteria, the potential of different pollutants to harm the environment is assessed and expressed in the α_i -Factor. In general other impact assessment systems can be chosen and the factors shown in this example can be replaced by them if there is a scientific sound basis for them to avoid misleading information.

The partial water degradation footprint is calculated with: [3]

$$W_{\mathrm{FD}} = \sum \alpha_i \cdot E_i \qquad (2)$$

where

W_{FD} is the partial water degradation footprint, expressed in liters H_2Oe,

α_i is the characterization factor for each E_i which can be obtained for each pollutant (i), and

E_i is the amount of pollutants emitted to water.

Tableau 38 - Transformation of pollutants to indicator results

Pollutants to water	E_i Value (mg) from site	Requirement on waste water (mg/l Appendix Nr 22 to German Waste water regulation (AbwV)	α_i -Factors for calculating the CWV (l- H2Oe /mg)	Evaluation result (l- H2Oe)
Organic substances	1000	75	0,013	13
N total	1000	13	0,077	77
Heavy metals	1000	2	0,500	500
Hg	1000	0,001	1000	1000000
Cd	1000	0,005	200	200000
Cr	1000	0,05	20	20000
Zn	1000	0,2	5	5000
Cu	1000	0,1	10	10000
Ni	1000	0,05	20	20000
Pb	1000	0,05	20	20000
Sn	1000	0,2	5	5000

Often parameters of pollutants are collected as aggregated figures. This is true in this example for heavy metals. In that case the most critical figure is chosen in a conservative approach. This calculation shows a very high importance for the heavy metals subsequently (Tableau 39). For a better interpretation of the results and the assessment of the variability, a scenario analysis is needed because it can show, how the system changes if lower factors will be integrated into the calculation. In this case, the importance of heavy metals go down significantly (Tableau 40). In this scenario, both sites are in the same region or in two different regions where for one region the calculation factors are not available and the German factors have been used as a default value.

To take the same two sites approach as in the water scarcity footprint, two different sites of a chemical company are shown in this example.

Tableau 39 - Corporate sites partial water degradation footprint with conservative evaluation factors for heavy metals

Location	Pollutants to water	E_i Value (metric tonnes) from sites	Requirement on waste water (mg/l Appendix Nr 22 to German Waste water regulation (AbwV)	α_i -Factors for calculating the CWV (l- H2Oe /mg)	Degradation waterfootprint W_{FD} (Mio m^3 H2Oe)
Site 1	Organic substances (COD)	6.500	75	0,013	86,7
	N total	1.230	13	0,077	94,6
	Heavy metals	14	0,001	1000,000	14000,0
Site 2	Organic substances (COD)	1.344	75	0,013	17,9
	N total	172	13	0,077	13,2
	Heavy metals	2	0,001	1000,000	1500,0
Other sites	Organic substances (COD)	11.856	75	0,013	104,6
	N total	1.498	13	0,077	107,8
	Heavy metals	6	0,001	1000,000	15500,0
Total	Organic substances (COD)	**19.700**			**209**
	N total	**2.900**			**208**
	Heavy metals	**22**			**31000**
	Total				**31417**

Editing note: Obtain editable version of the table.

Tableau 40 - Corporate sites partial water degradation footprint with lower evaluation factors for heavy metals

Location	Pollutants to water	E_i Value (metric tonnes) from sites	Requirement on waste water (mg/l Appendix Nr 22 to German Waste water regulation (AbwV)	α_i -Factors for calculating the CWV (l- H2Oe /mg)	Degradation waterfootprint W_{FD} (Mio m^3 H2Oe)
Site 1	Organic substances (COD)	6.500	75	0,013	86,7
	N total	1.230	13	0,077	94,6
	Heavy metals	14	0,05	20,000	280,0
Site 2	Organic substances (COD)	1.344	75	0,013	17,9
	N total	172	13	0,077	13,2
	Heavy metals	2	0,05	20,000	30,0
Other sites	Organic substances (COD)	11.856	75	0,013	104,6
	N total	1.498	13	0,077	107,8
	Heavy metals	6	0,05	20,000	310,0
Total	Organic substances (COD)	**19.700**			**209**
	N total	**2.900**			**208**
	Heavy metals	**22**			**620**
	Total				**1037**

In the example of Tableau 41, one site is located in Germany (Site 1) and another site somewhere else in the EU (Site 2). The source for the EU figures are publicly available as well [4]. For this situation, two different sets of factors are used specifically for the region, were the emissions occur. Because there are no factors for Organic substances available for the EU, the default value was applied. For the “Other sites”, the default values have been used as well, because there is only a low level of granularity available for the basic data and there are no figures for all regions in the world available.

Tableau 41 - Corporate sites partial water degradation footprint with by assessing different sites in different regions

Location	Pollutants to water	E_i Value (metric tonnes) from sites	The Water Framework Directive (2000/60/EC) and (2006/118/EC) of EU	α_i - Factors for calculating the CWV in the EU (l- H2Oe /mg)	α_i - Factors for calculating the CWV in Germany (l- H2Oe /mg)	Degradation waterfootprint W_{FD} (Mio m^3 H2Oe)
Site 1, Germany	Organic substances (COD)	6.500			0,013	86,7
	N total	1.230			0,077	94,6
	Heavy metals: Cr	14			20,000	280,0
Site 2, EU	Organic substances (COD)	1.344	n/a	n/a	0,013	17,9
	N total	172	67	0,015		2,6
	Heavy metals: Cr	2	0,0375	26,667		40,0
Other sites	Organic substances (COD)	11.856			0,013	158,1
	N total	1.498			0,077	115,2
	Heavy metals: Cr	6			20,000	128,0
Total	Organic substances (COD)	**19.700**				**263**
	N total	**2.900**				**204**
	Heavy metals	**22**				**448**
	Total					**915**

10.1.4 Interpretation

Different types of water footprints can be calculated. Depending on the goal and scope of such a study, a water scarcity footprint as well as a partial water degradation footprint can be obtained by using data that companies report in their annual reports or in other publication frameworks. In this example only the impacts directly associated with site water consumption or site emissions are accounted for.

The corporate sites partial degradation water footprints describe partial water degradation of the company related to direct emissions to water only. In order to make the direct water degradation footprint complete, the water degradation footprint associated with air and soil emissions affecting water would have to be calculated.

10.1.5 Bibliography

[1] Pfister S, Koehler A and Hellweg S (2009). Assessing the environmental impacts of freshwater consumption in LCA. Environmental Science and Technology, 43(11) 4098-4104.

[2] Powell, J.C., Pearce, D., Brisson, I., Valuation for Life cycle Assessment of waste management options, CSERGE Working Paper WM 95-07 (1995), ISSN: 0967-8875

[3] Saling, P., Kicherer, A., Dittrich-Kraemer, B., Wittlinger, R., Zombik, W., Schmidt, I., Schrott, W., Schmidt, S.; Eco-Efficiency Analysis by BASF: The Method.; Int J LCA, 7 (4), (2002), 203-218.

[4] The Water Framework Directive (2000/60/EC) and the Directive on the protection of groundwater against pollution and deterioration (2006/118/EC)

10.2 Example P – Water scarcity footprint of a company, accounted for direct and indirect water scarcity (using an aluminium company as an example)

10.2.1 Goal and scope definition

This is a fictitious example.

The goal of the study is to determine the water scarcity footprint of an organization, i.e. an aluminium company which owns 4 different bauxite mines, 3 alumina refiners and 8 different aluminium smelters, but does not own or control plants for semi-finished products. The organization has the financial and operative control over the facilities included in this study. Therefore it accounts for the 100% of the potential environmental impacts related to water of their operations.

An additional goal of the study is to determine the direct and indirect water scarcity footprint of the primary aluminium which the company supplies.

The overall activity of the company is to produce bauxite, alumina and primary aluminium ingots. The reporting unit is the annual production of the company.

Two different boundaries are considered, i.e. the boundary for the organization and the cradle-to-gate boundary for the organization, see Figure A.1 in ISO 14046. As shown in Figure 10, the cradle-to-gate system includes the supply of the most important materials and energy. The term “cradle-to-gate” means that the further processing, use and end-of-life stages of specific aluminium products are excluded from the system.

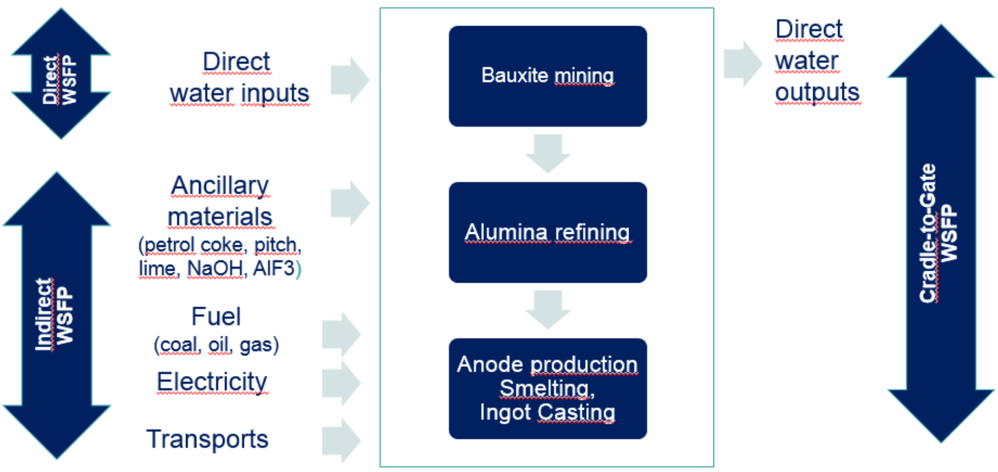


Figure 10 – Direct, indirect and cradle-to-gate water scarcity footprint (WSFP) of an aluminium company

The annual production of the smelters is 2,41 Mio t of primary aluminium for which 4.7 Mio t of alumina are needed. The alumina refiners of the company produce annually 8,7 Mio t of alumina, from which they sell 4.7 Mo tonnes to the own smelters and 4,0 Mio t to third companies.

For the annual production of the refiners of 8,7 Mio t alumina, 25,3 Mio t of bauxite are needed. The mines of the company produce annually 30 Mio t of Bauxite, from which they sell 25,3 Mio tonnes to the own refineries 4,7 t to third companies.

Consequently, the reporting unit of the aluminium company is the supply of 2,41 Mio t of primary aluminium, 4,0 Mio t of alumina and 4,7 Mio t of bauxite.

10.2.2 Inventory analysis

The company collected from each of the plants data on annual water inputs and outputs, in order to determine the direct water consumption. Furthermore, data on annual ancillary material consumption, fuel and electricity consumption and transports were collected to determine the indirect WSFP.

The annual freshwater consumption includes the difference between the freshwater input and the water discharge and, for bauxite mines, it also includes the water content of the shipped bauxite.

The freshwater input is determined by quantifying the water which is supplied via water pipes by external suppliers, from site-owned groundwater sources or from rivers or lakes.

Note: Water coming from external suppliers is part of indirect WFP

The water discharge is determined as the volume of water which annually leaves the plant in sewage pipes minus the annual volume of storm water which flows through those pipes. Water evaporation from the area of the plant is not considered as it is assumed that the same volume of water had evaporated before the plant had been built.

Note: Water going to sewage pipes managed by external company is part of indirect WFP

For each site the local water scarcity index $CF_{Sc,L}$ is determined using the google earth version of Pfister et al [1]

In ISO/DIS 14064, subclause 5.3.2, it is stated:

Water inputs or water outputs of different resource types, different quality, different form, different location with different environmental condition indicators or different timing shall not be aggregated in the inventory phase. Aggregation may be performed at the impact assessment phase.

As averaging includes aggregation, “conventional” averaging of freshwater consumption on the inventory level, as used for other LCI data, is not permitted for the determination of the water footprint, if the relevant sites are located in areas with different water scarcity. Therefore, for the purpose of this study, no averages of the water consumption of the aluminium plants have been calculated.

10.2.3 Impact assessment

10.2.3.1 Direct water scarcity footprint

In this example, it has been decided to calculate the annual direct water scarcity footprint of a plant *n* as follows:

$$WF_{Sc,n} = C_n \times \frac{CF_{Sc,L}}{CF_{Sc,Glo}} \quad (1)$$

where

$WF_{Sc,n}$ is the direct water scarcity footprint of the plant *n*

C_n is the annual freshwater consumption of this plant, i.e. the quantity of water which has evaporated, integrated into sold products or waste or directly released into the sea , and

$CF_{Sc,L}$ is the characterization factor for the water scarcity impact, being here the water scarcity index of the location where the plant operates.

$CF_{Sc,Glo}$ is the average global water scarcity index, i. e. 0,6

The direct water scarcity footprint parameters of the different bauxite mines, alumina refiners and smelters of the aluminium company are shown in Tableau 42, Tableau 43, and Tableau 44.

Tableau 42 – Direct water consumption and direct water scarcity footprint of bauxite mines

	CF (WSI)	Shipped bauxite	Water contained in bauxite	Total fresh water input	Total water discharge	Fresh water consumption	Direct WSFP, total	Direct WSFP per t of bauxite
		Mt	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3 H_2Oe	m^3 H_2Oe/t
Mine 1	0,013	13,0	1,3	2,4	1,1	2,6	0,05	0,004
Mine 2	0,24	8,6	0,7	1,1	0,0	1,8	0,72	0,083
Mine 3	0,13	2,5	0,3	0,9	0,3	0,9	0,20	0,081
Mine 4	0,06	5,6	0,5	3,2	1,6	2,1	0,21	0,038
Total		**30**					**1,18**	**0,040**

Tableau 43 – Direct water consumption and direct water scarcity footprint of alumina refiners

	CF (WSI)	Shipped alumina	Freshwater input	Net water discharge	Net water consumption	Direct WSFP	Direct WSFP per t of alumia
		Mt	Mm^3	Mm^3	Mm^3	Mm^3 H_2Oe	m^3 H_2Oe/t
Refiner 1	0,01	4,5	17,8	6,8	11,0	0,2	0,04
Refiner 2	0,34	1,7	7,6	1,2	6,4	3,6	2,13
Refiner 3	0,16	2,5	26,1	12,8	13,3	3,5	1,42
Total/Average		8.7				7,4	0,85

Tableau 44 – Direct water consumption and direct water scarcity footprint of aluminium smelters

Plant name	CF (WSI)	Shipped aluminium	Freshwater input	Net water discharge	Net water consumption	Direct WSFP	Direct WSFP per t
		Mt	Mm^3	Mm^3	Mm^3	Mm^3 H_2Oe	m^3 H_2Oe/t
Smelter 1	0,010	0,23	0,80	0,67	0,13	0,0022	0,009
Smelter 2	0,069	0,42	1,20	0,79	0,41	0,047	0,112
Smelter 3	0,032	0,15	0,30	0,17	0,13	0,0068	0,046
Smelter 4	0,100	0,09	0,11	0,06	0,05	0,0083	0,093
Smelter 5	0,011	0,48	3,60	2,10	1,50	0,029	0,059
Smelter 6	0,051	0,35	1,90	1,35	0,55	0,047	0,134
Smelter 7	0,014	0,52	2,90	1,89	1,01	0,023	0,044

Smelter 8	0,022	0,17	3,20	2,60	0,60	0,022	0,127
Total		2,41				0,185	0,077

The direct water scarcity footprint of the company is 8,7 Mm^3 H_2Oe, where:

- the bauxite mines contribute to 1,18 Mio m^3 H_2Oe,
- the alumina refiners contribute to 7.4 Mio m^3 H_2Oe, and
- the smelters contribute to 0,18 Mio m^3 H_2Oe.

10.2.3.2 Indirect water scarcity footprint

In order to determine the indirect WSFP of the different plants of the companies, data about the consumption of ancillary products and energy of the bauxite mines, the refiners and the smelters were collected. For each of those inputs the WSFP data has been determined via a data provider.

Special consideration was given to the electricity supply of the smelters. Each smelter reported its electricity consumption and the source of electricity (dedicated power plant, national grid or regional grid). Then for each dedicated power plant the WSFP per MWh has been determined. For those smelters which got the electricity from a national or a regional grid, the WSFP per MWh has been determined by

- selecting a representative number of power plants from this grid,
- determining the total WSFP and the total electricity production, plant-by-plant,
- dividing the total WSFP by the total electricity production of these power plants.

The result is shown in Tableau 45.

Tableau 46, Tableau 47, and Tableau 48 show the calculation of the indirect WSFP of the bauxite mines, the alumina plants and the smelters.

Note: The WSFP associated with the ancillary materials, fuels and electricity has been calculated as the production weighted WSFP of the different suppliers in the background. However, this work has been done in and by the background database supplier and is used as a generic information.

Tableau 45 - Calculation of the annual WSFP of the electricity supply of the aluminium smelters

Plant name	Shipped alumina	Electricity consumption		WSFP of electricity	Annual WSFP by electricity
	Mt/a	MWh/t	MMWh/a	m^3 H_2Oe/MWh	Mm^3 H_2Oe/a
Smelter 1	0,23	14,5	3,3	0,23	0,77
Smelter 2	0,42	13,8	5,8	0,16	0,93
Smelter 3	0,15	15,1	2,3	0,69	1,56
Smelter 4	0,09	15,6	1,4	0,52	0,73
Smelter 5	0,48	12,9	6,2	0,32	1,98

Smelter 6	0,35	14,8	5,2	0,12	0,62
Smelter 7	0,52	14,0	7,3	0,09	0,66
Smelter 8	0,17	13,7	2,3	0,85	1,98
Total	2,4	14,0	33,8	0,3	9,2

Tableau 46 - Direct and indirect WSFP of bauxite mines

Type of input	WSFP per type of input[3]		Input per t of bauxite		Total production of bauxite mines	WSFP
	Amount	Unit	Amount	Unit	Mt	Mm^3 H_2Oe
Heavy oil	2,0	m^3 H_2Oe/t	0,20	Kg/t	30	0,012
Diesel oil	3,1	m^3 H_2Oe/t	0,30	Kg/t	30	0,028
Electricity	0,35	m^3 H_2Oe/MWh	0,90	MWh/t	30	0,009
			Total indirect WSFP			0,05
			Total direct WSFP of bauxite mines (see Tableau 42)			1,18
			Total direct and indirect WSFP			1,23

Tableau 47 - Direct and indirect WSFP of alumina refiners

Type of input	WSFP per type of input[4]		Input per t of alumina		Total production of alumina refiners	WSFP
	Amount	Unit	Amount	Unit	Mt	$Mm^3 H_2Oe$
Caustic Soda	2,5	m^3 H_2Oe/t	79	Kg/t	8,7	1,7
Clacined Lime	0,09	m^3 H_2Oe/t	40	Kg/t	8,7	0,03
Heavy oil	2,1	m^3 H_2Oe/t	122	Kg/t	8,7	2,2
Natural gas	1,7	L H_2Oe/Nm^3	139	Nm^3/t	8,7	2,0
Electricity	0,35	m^3 H_2Oe/MWh	79	Kg/t	8,7	0,24

[3] Simplified values for the sake of the example. Do not reuse.

[4] Simplified values for the sake of the example. Do not reuse.

Sea transport (Bauxite)	0,008	L H_2Oe/tkm	3 059	tkm/t	8,7	0,22
			Total indirect WSFP			6,4
			Total direct WSFP of bauxite mines (Tableau 43)			7,4
			Total direct and indirect WSFP			13,7

Tableau 48 - Direct and indirect WSFP of aluminium smelters (including anode plants)

Type of input	WSFP per type of input[5]		Input per t of aluminium		Total production of aluminium smeleters	WSFP
	Amount	Unit	Amount	Unit	Mt	Mm^3H_2Oe
Petrol coke	0,26	m^3 H2Oe/t	295	Kg/t	2,41	0,188
Pitch	0,48	m^3 H2Oe/t	74	Kg/t	2,41	0,085
Refractory	20	m^3 H2Oe/t	10	Kg/t	2,41	0,500
Steel	4,8	m^3 H2Oe/t	6,0	Kg/t	2,41	0,073
Cathode Carbon	0,26	m^3 H2Oe/t	6,0	Kg/t	2,41	0,004
AlF3	1,4	m^3 H2Oe/t	16	Kg/t	2,41	0,055
Natural gas	1,7	L H_2Oe/Nm3	39	Nm^3/t	2,41	0,156
Sea transport (Alumina)	0,008	L H_2Oe/tkm	13 423	tkm/t	2,41	0,262
Electricity	0,27	L H_2Oe/MWh	14,0	MWh/t	2,41	9,23
			Total indirect WSFP			10,5
			Total direct WSFP (see Tableau 44)			0,18
			Total direct and indirect WSFP			10,7

10.2.3.3 Direct and indirect WSFP of the aluminium company and its products

The summary is shown in Tableau 49. The direct and indirect WSFP is

- 1,2 Mm^3 H_2Oe for bauxite mines;
- 13,7 Mm^3 H_2Oe for alumina refiners;
- 10,7 Mm^3 H_2Oe for aluminium smelters;

[5] Simplified values for the sake of the example. Do not reuse.

- 25,7 Mm^3 H_2Oe for all plants from which 18,6 Mio m^3 H_2Oe is caused by the production of primary aluminium and the bauxite and alumina needed for primary aluminium.

The direct and indirect WSFP per tonne of bauxite shipped to third parties is 0.041 m^3 H_2Oe.

The direct and indirect WSFP per tonne of alumina shipped to third parties is 1.70 m^3 H_2Oe. This is the sum of the specific WSFP of the refineries related to 1 tonne of alumina, i.e. 1.58 m^3 H_2Oe/t and the specific WSFP of bauxite mines which is related to the 2,88 tonnes of bauxite needed per tonne of alumina, i.e. 2,88 x 0,041 m^3 H_2Oe/t.

Finally, in that specific fictive example, the direct and indirect WSFP per tonne of aluminium is 7,74 m^3 H_2Oe/t as shown in the last column of Tableau 49.

Tableau 49 - Direct and indirect WSFP of primary aluminium produced by the aluminium company

	Annual production		WSFP (direct)		WSFP (direct & indirect)		WSFP (direct & indirect)	
	Mt/a		Mm^3 H_2Oe		Mm^3 H_2Oe		m^3 H_2Oe per t of product	m^3 H_2Oe per t of primary aluminium
	total	for own smelters	total	for own smelters	total	for own smelters		
Mines	30	13,4 (47%)	1,18	0,53	1,23	0,56	0,041	0,23
Refineries	8,7	4,7 (54%)	7,36	3,94	13,73	7,36	1,58	3,05
Own smelters	2,41	2,41 (100%)	0,185	0,18	10,73	10,73	4,45	4,45
Total			8,72	4,66	25,70	18,65		7,74

10.2.4 Interpretation

The plants with the highest WSFP per tonne of product can be identified. For them, it can be, for example, recommended to include water consumption into the list of environmental aspects to be assessed on a regular basis and define reduction goals as a part of their environmental management system.

The direct and indirect WSFP per tonne of aluminium (i.e. 7,74 m^3 H_2Oe/t in this fictive example) can be benchmarked against the WSFP of global primary aluminium which is reported for the year 2010 by the International Aluminium Institute (IAI) as 9,6 m^3 H_2Oe per t of primary aluminium, based on data as collected in 2010. However, before any comparison is done, it is important to verify that the same methodology was used to assess the WSFP of both systems (our “own” company and the average value of IAI). Indeed, differences can occur in the inventory primary data collection at sites, in the databases used to assess indirect WSFP of inputs, in the impact assessment method, etc.

It has been recognized that that the WSFP does not describe the water degradation footprint of the company. Therefore, in addition to the data collection for water scarcity, in order to have a complete water footprint that includes water degradation footprint in addition to water scarcity footprint, the company has to collect data on emissions to air, soil and water (including thermal release) and determine indicator results related to water degradation footprint, such as, water ecotoxicity, water acidification, water eutrophication, water pollution from ionizing substances, thermal pollution, etc.

10.2.5 Bibliography

[1] Pfister S, Koehler A and Hellweg S (2009). Assessing the environmental impacts of freshwater consumption in LCA. Environmental Science and Technology, 43(11) 4098-4104.

11 Issues arising in water footprint studies

11.1 Seasonality

Editing note: Proposed by Taikan (leader), Brad, and Guoping, on Jan 21, 2015.

See relevant sections of ISO 14046: Section 5.2.4.1 g) and h), 5.4.4.2.

ISO 14046 (5.2.4.1 and 5.4.4.2) encourages to consider seasonal changes and temporal aspects, including timing of water use and length of water storage, if relevant.

Seasonality might be an important issue to be considered under contexts such as:

1) water demand fluctuates through the year, e.g., seasonal demand for crop irrigation and industrial processes not operated the entire year,

2) water availability varies significantly throughout the year, especially regarding to surface water, and/or

3) modeling impact assessment characterization factors for water availability footprint in region with high variation in precipitation or strong storage influence from natural (e.g. glaciers) or artificial (e.g. dams) storages.

Temporal aspects, including seasonality, can be significant particularly in already water stressed river basins because critical threshold would be exceeded at some timing within a year.

Example D illustrates temporal aspects of the interference of artificial reservoirs that reduces water availability when water demand and potential environmental impacts are low consequently, and increases water availability when water demand and potential environmental impacts are relatively high. Example D shows that assessment without considering seasonality would produce a result significantly different than the one with considering seasonality, showing that considering seasonality is important in such context.

The impacts and benefits are often presented separately because there is no consensus to derive a net impact or benefit results. However, it is not uncommon that studies address impacts and benefits together. This needs to be done in a careful way to avoid misinterpretation. Net result might be an acceptable simplification for impacts and benefits occurring in the same place (as for example in Example D) with little risk of misinterpretation. This is the case at least for human impacts. For ecosystems impacts, whether dams are a benefits or an impact is an active area of research.

Where significant irrigation and significant seasonality exist, there is usually significant capacity of storage as well. Therefore there is a danger simply applying monthly water stress indices for monthly crop irrigation use. It might be important to expand the system boundary to include the storages and the way the storages are operated. Although irrigation are often occurring during dry period, water may have been collected during periods when water is abundant and therefore when water stress indices were low. In some regions, water intensive crops are only grown when water supplies are enough and water use has low potential impacts. Hence annual assessments might overestimate stress on water.

11.2 Use of a baseline

Editing note: Proposed by Sarah.

Relevant sections of ISO 14064: Section 5.2.2(n), Section 5.2.4.1, Section 6.2(d)(8).

In a water footprint study, a baseline is defined when the system under analysis is associated with modification of a pre-existing situation. This may arise, for example, when:

• A dam is created in order to generate hydroelectricity: the land to be occupied by the dam is flooded and so is modified from its previous use. Evaporation rates change because water evaporates from the surface of the reservoir rather than the previous terrestrial ecosystem, and the hydrology of the drainage basin is changed because the water flow from the dam is now regulated.

• Agriculture and forestry are practised: irrigation of land may cause modification of the water flows in one or more drainage basins, and non-irrigated agriculture and forestry may have the same effect through increased or decreased evapotranspiration and changes in soil moisture levels.

• Rainwater is harvested and stored: rainwater is diverted to storage tanks and may be used at different times of the year.

The baseline may be the actual situation immediately prior to implementation of the current system under analysis, a so-called theoretical "natural" situation that would exist in the absence of human intervention, or an anticipated alternative situation if the current system under analysis was not to be implemented in future.

An example is provided in Example D for evaporation from a reservoir.

Additionally the baseline may be a specific time period that is compared with the current situation. A typical example is performance tracking in organisations. Here, the baseline may be the organisation's performance in a particular year, and the results for subsequent years are compared with that year.

11.3 Evaporation, transpiration and evapotranspiration

Editing note: Proposed by Tim.

Evapotranspiration (ET) is the sum of transpiration from plants and evaporation from wet surfaces (e.g. water bodies or wet soils). In a forest, ET is dominated by transpiration whereas in paddy fields evaporation from open water is a much higher proportion. Generally there is little value in separating evaporation from transpiration and ET represents the total water loss from the surface to the atmosphere. The ET at a particular location and time is a function of the weather; the type and stage of growth of the vegetation; and the soil water content; and can be estimated from agrometeorological models. Human activities (such as a change of land use or management; irrigation water management; change of crop type or variety) may result in a change in ET. The impacts of such a change may be positive or negative.

NOTE1 Green Water. When the water used by plants (ET) is from rainfall at the point where it falls, this is sometimes referred to as "green water". Rainfed agriculture or forestry only uses green water, whereas irrigated crops may also use water withdrawn from surface or groundwater resources.

NOTE2 Green Water Footprint. The term "green water footprint" has been adopted by some to represent sum of green water used by plants / vegetation over a given period of time (e.g. m^3/a) or per unit of production (e.g. m^3/t). This does not correspond with the definition of water footprint in ISO 14046 (which explicitly refers to impacts) and therefore the term is not used in this TR.

11.4 Water quality

See relevant section of ISO 14046: Section 5.2.4.1 c).

Water quality is relevant to assess a water degradation footprint and a water availability footprint.

1) Water degradation footprint

Emissions with fate in water create environmental impacts which when considered comprehensively constitute a water degradation footprint. Impacts categories affected by water quality are:

- Freshwater and marine eutrophication (e.g. from phosphorus and nitrogen emissions)

- Freshwater and marine ecotoxicity (e.g. from mineral and organic contaminants, such as pesticides and heavy metals)
- Freshwater and marine/ocean acidification (e.g. from AOX, acids, H2S, CO2, ...)
- Human toxicity (including carcinogenic and non-carcinogenic contaminants)
- Ionizing radiations
- Heat release
- Other relevant categories

The impact on each of these impact categories can be expressed using either midpoint or endpoint units.

These environmental mechanisms lead to impacts on the areas of protection ecosystem quality and human health. (See for example example H)

2) Water availability footprint

From the standard: “Water quality can also influence availability, e.g. if the quality is not sufficient to meet the users needs.” (section 3.3.16). Hence, a negative change in water quality between the input and output of the system can cause lower availability of the resource - in addition to specific environmental impact categories described above as water degradation - if the water is not longer functional for another human use because of too low quality. (See example H for an application of this).

11.4.1 Relevant air and soil (and water) emissions

See relevant sections in ISO 14046: 1, 3.3.7, 5.2.4.1, 5.3.2 f).

Some users might be confused as why air and soil emissions should be included in a water footprint, when, apparently water footprint is about water and not air and soil pollution. This is because a fraction of pollutants emitted to air or soil will end up into the water (called fate) and (potentially) affects its quality. If it affects its quality, it will therefore contribute to water degradation footprint and/or water availability footprint.

An emission to air or soil that is relevant to consider in the water footprint inventory is an emission that will end up into the water (i.e. have its fate in water) and affect the impact categories considered in the scope.

This means that only the fraction of the emission to air or soil that ends up into the water contributes to water footprint. For example, if freshwater ecotoxicity has been considered as an impact category into the scope when assessing the water degradation footprint of an incinerator, a certain fraction of pollutants emitted at the stack will end up into freshwater and contribute to freshwater ecotoxicity. This fraction will depend on the pollutant properties (e.g. whether it is short or long lived, etc.) as well as technological (e.g. stack high) and environmental conditions (e.g. wind speed, rainfall frequency and intensity, distance between the stack and freshwater body, etc.). Note that in practice, fate models (such as USEtox [12]) exist to model the fraction of a pollutant emitted into the air (or soil) that will end up into water bodies. Therefore, in LCA practice, it is often possible to simply record the amount of pollutants emitted to air and soil (and of course water) into the water footprint inventory analysis, and the impact assessment models calculate themselves the fraction of this pollutant emitted to air or soil that will end up into water bodies and therefore contributing to freshwater ecotoxicity.

Also, only emissions contributing to the impact categories considered in the scope need to be included in the water footprint inventory. For example, if the scope has decided to focus only on water acidification footprint, only acidifying substances need to be considered in the inventory (e.g. if only aquatic acidification has been selected into the scope of the study, substances only contributing to aquatic ecotoxicity but not to aquatic acidification do not need to be included into the water footprint inventory).

See examples J, H, K, L, I, M, N, and O that include emissions.

Example J has included relevant air and soil emissions implicitly into its assessment (not shown here) to calculate all relevant indicators for water degradation footprint (in this case Freshwater ecotoxicity, Freshwater acidification, Marine acidification, Freshwater eutrophication, Marine eutrophication, Ionizing radiation (impact on freshwater ecosystems), Thermally polluted water, Marine water ecotoxicity as well as Human toxicity (carcinogens), Human toxicity (non-carcinogens) and Impact on human health from Ionizing radiation). This is actually the only example in this document that aims at calculating a comprehensive water degradation footprint.

Example H includes emissions causing to water eutrophication. Example K includes some emissions causing Freshwater eutrophication, Terrestrial ecotoxicity, Freshwater ecotoxicity and Marine ecotoxicity. Example L includes, implicitly in the calculations, emissions to air and soil and water contributing to aquatic eutrophication, aquatic acidification and aquatic ecotoxicity. Those three examples do not calculate a comprehensive water degradation footprint but have a complete scope for the impact categories that are being assessed.

Example N aims at being comprehensive. However, it still missing to assess several of the less “traditional” water degradation impact categories such as marine ecotoxicity, marine eutrophication, marine acidification, and impacts related to thermal release.

Examples I, M, and O only include emissions to water. Those two examples are therefore an incomplete (that could be called partial or non-comprehensive) water degradation footprint (i.e. a water degradation footprint looking only at water pollution from emissions directly into water but not from emissions to air and soil ending up to water).

Example E includes relevant emissions affecting water availability.

As in any LCA, the extent of the list to be considered depends on the constraints of the study as well as the types of impact categories considered.

In a comprehensive water footprint, the list of pollutants considered should be as extensive as practically possible. For background processes, current life cycle inventory background database can typically consider hundreds or thousands pollutants. For foreground processes, the number of pollutants to be considered can vary between a few (if only some specific pollutants are emitted by a process) to tens (e.g. types of pesticides and fertilizers used in agriculture) or hundreds (e.g. if assessing the water footprint of factories including combustion or incinerations or landfill leachates). Note that several or most of those emissions are not directly measured but calculated or modeled based on primary data (e.g. amount of NH_3 emitted to air from fertilizers in a field or SO_2 emitted to air in from diesel truck tailpipe will be calculated, respectively, based on typically emissions factors for NH_3 based on the N content of (and type of) fertilizer or S content of the fuel used respectively).

NOTE: Emissions of CO_2 are included if the marine acidification impact category is chosen in the scope within the list of selected impact categories as it contributes to ocean acidification and therefore to marine water acidification footprint. Note that this is not a double counting with carbon footprint as the CO_2 is considered in that case as an acidifying gas and not gas contributing to global warming (similar to SO_2 that can contribute to both acidification of lakes and to human health impacts caused by secondary particulate matter formation).

11.5 Choice of indicators along the environmental mechanism

See relevant section of ISO 14046: Section 5.4.2.

The list of impact categories as well as the respective environmental indicators considered needs to be indicated in the scope of the study.

The indicators can be chosen along the environmental mechanism of the cause effect chain of each impact category. The choice can be geared based on the uncertainty associated with the cause effect chain.

Several impact categories can contribute to one area of protection. For example, freshwater ecotoxicity (expressed for example in CTUe) and freshwater eutrophication (expressed for example in kg P-eq) can contribute to impacts on freshwater ecosystem (expressed for example in PAF-m^3-y). It is possible to express the final results keeping freshwater ecosystem into two separate impact categories, i.e., freshwater ecosystem impact caused by freshwater ecotoxicity (expressed in PAF-m^3-y) and freshwater ecosystem impact caused by freshwater eutrophication (expressed in PAF-m^3-y), or, if reduction of the number of information presented is desired, one can also present both impact categories aggregated into one indicator (being here freshwater ecosystems impact).

Also, one single midpoint can contribute to several area of protections. For example, water scarcity footprint (expressed for example in m^3 H_2Oe) can contribute to both impacts on human health (expressed for example in DALY) and impacts on ecosystem quality (expressed for example in PAF-m^3-y).

Example H provides an example where the same impacts are presented using both a profile of midpoint indicators and endpoint indicators.

Therefore, the choice of indicator can also be influenced by the level of details at which one wants to present the results and type of communication envisioned.

11.6 Identification of foreseen consequences of the excluded impacts

Editing note: Proposed by Sarah.

Relevant sections of ISO 14064: Section 5.2.2(k) and last sentence, Section 5.4.5, Section 5.4.6, Section 5.4.7.

Prior to detailed data collection and/or modelling in a water footprint study of a product, process or organisation, the scope is defined for the study. Amongst other things, this involves determining the type of water footprint study to be undertaken (e.g. water scarcity footprint, water eutrophication footprint, water footprint profile, etc.). The choice of a non-comprehensive water footprint study is justified by identifying the foreseen consequences of the excluded impacts and describing why they are insignificant or why they are not of interest for the commissioner (within the context of the goal of the study). These foreseen consequences may be uncertain or unknown because there are no data currently available either due to lack of scientific analysis of the issue(s) and/or because the impacts have not yet occurred (for example, the impacts associated with future intensification of agricultural systems).

The identification of foreseen consequences is done in an iterative process that involves estimating and/or modelling the input and output data and associated environmental impacts for the system under analysis (see Section 5). The exclusion of certain impact categories (and therefore the type of water footprint study) may be revisited later in the study depending on the insights gained during the analysis.

Editing note: Maybe HERE PROVIDE A BRIEF SUMMARY OF HOW THIS ISSUE IS ADDRESSED IN THE CASE STUDIES ?

11.7 Sensitivity analysis

Editing note: Proposed by Sarah.

Sensitivity analysis is a procedure to determine how changes in data and methodological choices affect the outcome of the study (ISO 14044, Section 4.4.4.2). It may be undertaken when there is uncertainty over the accuracy of data and/or methods used in a study. Aspects that may be investigated using sensitivity analysis include:

- Geographical and temporal resolution of data (average versus more process-specific data),
- Definition of system boundary (omission versus inclusion of life cycle stages and/or specific unit processes),
- Allocation procedure,

- Impact assessment method, and/or
- Value choices (including weighting).

Examples are provided in Example D for temporal resolution of data (the effect of accounting for seasonality in a reservoir), and in Example C for use of different impact assessment methods.

Bibliography

Editing note: Do not look at the bibliography yet. It will be aligned with the rest of the document once the content of the document will be finalized.

NOTE: The bibliography may contain references to methods that are not fully compliant with ISO 14046.

[3] Pfister S, Koehler A and Hellweg S (2009). Assessing the environmental impacts of freshwater consumption in LCA. Environmental Science and Technology, 43(11) 4098-4104.

[4] Keating B A, et al. (2003). An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy, 18(3-4) 267-288.

[5] Ridoutt BG and Pfister S (2010). A revised approach to water footprinting to make transparent the impacts of production and consumption on global freshwater scarcity. Global Environmental Change, 20(1) 113-120.

[6] Yano S, Hanasaki N, Itsubo N, Kondo T, Oki T (2012): Global Water Footprint Factor for evaluating potential impacts on freshwater availability. The International Journal of Life Cycle Assessment submitted.

[7] S. Pfister S, Baumann J (2012): Monthly characterization factors for water consumption and application to temporally explicit cereals inventory, Paper presented at the 8th International Conference on LCA in the Agri-Food Sector, Rennes, France,

[8] Jolliet O, Margni M, Charles R, Humbert Sb, Payet Jr, Rebitzer G, Rosenbaum R (2003) IMPACT 2002+: A New Life Cycle Impact Assessment Methodology. Int J Life Cycle Assess 8 (6):324-330

[9] [Saling, P.; Kicherer, A.; Dittrich-Kraemer, B.; Wittlinger, R.; Zombik, W; Schmidt, I.; Schrott, W.; Schmidt, S., Eco-efficiency analysis by BASF – The method, Int J. LCA 7 (4), 2002, 203-218.

[10] R. Baker, P. Saling, Comparing natural with chemical additive production, Feed Mix, 11, 1, 2003,12-14.

[11] Saling, P., Baker, R., Gensch, C.-O., Quack, D, Differences in Life-Cycle Assessment for the Production of Various Carotenoid Additives for use in Poultry Feeds, Journal of Sustainable Agriculture, 29 (1), 2006, 15-41.

[12] A.-M. Boulay, C. Bulle, J.-B. Bayart, L. Deschenes, and M. Margni, “Regional Characterization of Freshwater Use in LCA: Modeling Direct Impacts on Human Health,” Environmental Science & Technology, vol. 45, no. 20, pp. 8948–8957, 2011.

[13] A.-M. Boulay, C. Bouchard, C. Bulle, L. Deschênes, and M. Margni, “Categorizing water for LCA inventory,” The International Journal of Life Cycle Assessment, vol. 16, no. 7, pp. 639–651, 2011.

[14] R. Rosenbaum, T. Bachmann, L. Gold, M. Huijbregts, O. Jolliet, R. Juraske, A. Koehler, H. Larsen, M. MacLeod, M. Margni, T. McKone, J. Payet, M. Schuhmacher, D. van de Meent, and M. Hauschild, “USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment,” The International Journal of Life Cycle Assessment, vol. 13, no. 7, pp. 532–546, 2008.

[15] P.-O. Roy, L. Deschênes, and M. Margni, “Global spatially explicit indicators for life cycle impact assessment aquatic acidification,” In preparation, 2012.

[16] R. Helmes, M. A. J. Huijbregts, A. D. Henderson, and O. Jolliet, “Spatially explicit fate factors of freshwater phosphorous emissions at the global scale,” International Journal of Life Cycle Assessment, vol. 17, no. 5, pp. 646–654, 2012.

[17] S. Humbert and R. Maendly, “Empirical characterization model and factors assessing aquatic biodiversity damages of hydropower water use,” International Journal of Life Cycle Assessment, vol. Submitted, 2009.

[18] R. Van Zelm, M. Rombouts, J. Snepvangers, and M. A. J. Huijbregts, “Desiccation due to groundwater extraction in The Netherlands in LCIA.” Warsaw, Poland, 2008.

[19] M. M. Hanafiah, M. A. Xenopoulos, S. Pfister, R. S. E. W. Leuven, and M. A. J. Huijbregts, “Characterization Factors for Water Consumption and Greenhouse Gas Emissions Based on Freshwater Fish Species Extinction,” Environmental Science & Technology, vol. 45, no. 12, pp. 5272–5278, 2011.

[20] F. Verones, M. M. Hanafiah, S. Pfister, M. A. J. Huijbregts, G. J. Pelletier, and A. Koehler, “Characterization factors for thermal pollution in freshwater aquatic environments,” Environ. Sci. Technol., vol. 45, no. 17, p. 7608, 2011.

[21] Ridoutt BG, Pfister S, A new water footprint calculation method integrating consumptive and degradative water use into a single stand-alone indicator, Int J Life Cycle Assess (2013) 18:204–207

[22] Hoekstra A, Chapagain A, Aldaya M, Merkonnen M (2011) The Water Footprint Assessment Manual: setting the global standard. Earthscan, London, UK.

[23] S. F. Galeano, P. M Smorch, M. S. Richardson, “Application of Life Cycle Assessment to Supply Optimization”. ISIE 2011 Conference 6th International Conference on Industrial Ecology. Berkeley CA, June 9, 2011

[24] TRACI 2.0- Tool for the Reduction and Assessment of Chemicals and Other Impacts.US EPA 2010.

[25] Delton to S.F. Galeano, Mill Electricity Bus readings – Jan 9, 2013 .

[26] Yoshida, Takeo, Takao Masumoto, Ryoji Kudo, Tomoyuki Taniguchi and Naoki Horikawa (2012): Modeling of Basin-wide Water Circulation Incorporating Water Allocation and Management Schemes in Large Irrigated Paddy Areas, Journal of Irrigation, Drainage and Rural Engineering, 277, pp.9-19

[27] Masumoto, T., T. Taniguchi, N. Horikawa, T. Yoshida and K. Shimizu (2009): Development of a distributed water circulation model for assessing human interaction in agricultural water use, M. Taniguchi, W.C. Burnett, Y. Fukushima, M. Haigh & Y. Umezawa (Eds.), "From Headwaters to the Ocean: Hydrological Changes and Watershed Management," Taylor and Francis, pp.195-201