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The IDF Guide to Water Footprint Methodology for the Dairy Sector

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The IDF Guide to Water Footprint Methodology for the Dairy Sector

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THE IDF GUIDE TO WATER FOOTPRINT METHODOLOGY FOR THE DAIRY SECTOR

TABLE OF **CONTENTS**

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FOREWORD

Water is essential to life and to farming. Of all human activities, agriculture consumes the most water. FAO estimates that approximately 69% of all water withdrawn from renewable freshwater resources (rivers, lakes and groundwater) is used for irrigation, livestock and aquaculture. Freshwater withdrawals are expected to increase with the expanding human population, potentially worsening local water stress in many regions.

Agriculture therefore needs advanced tools for sustainable water management. The water footprint has become an important sustainability indicator for food production systems. Different methods and tools are available for measuring water use along the food chain and clear guidance is needed for interpretation of the results. To help improve the water footprint of the dairy sector and thus contribute to environmental sustainability, the International Dairy Federation (IDF) has produced this guide.

The *IDF Guide to Water Footprint Methodology for the Dairy Sector* provides the principles and requirements for water footprint assessment by describing the steps, data and models needed for life cycle assessment (LCA) calculations. The IDF guide maps the various water-related life cycle impact assessment methodologies, providing examples and recommendations on both consumptive water use and degradative water use models.

Reducing the amount of water used per unit of animal product is especially beneficial in regions that experience high water stress. These guidelines aim at supporting water management solutions through the identification of hotspots of water use and the establishment of progress indicators.

The *IDF Guide to Water Footprint Methodology for the Dairy Sector* was commissioned by the IDF Standing Committee on Environment. On behalf of the IDF, I would like to thank warmly all experts that contributed to its publication.

Nico van Belzen, PhD
Director General
International Dairy Federation
Brussels, January 2017

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1 INTRODUCTION

1.1. Background – the water challenge

Water is a finite and vulnerable vital resource. Water scarcity is an increasing problem that simultaneously affects society, the environment and food production. On farms, climate change is likely to exacerbate further the pressure on surface and groundwater supplies. At the same time, the projected increase in agricultural production required to feed the world over the coming decades makes water management a top priority, as approximately 70% of the world's freshwater is used by agriculture. The issues of water and agriculture are intertwined – without water there is no farming. So, to tackle the challenge of ensuring food security, the challenge of managing water resources must be met first.

Dairy and agriculture are water-intensive activities but water use and environmental impact can vary widely depending on the region, crop irrigation and type of crop. Depending on regional availability and other demands, irrigation accounts for up to 90% of water withdrawn from available sources. Furthermore, of these irrigation withdrawals for agriculture, approximately 15–35% worldwide are estimated to be an unsustainable use of water resources (Siebert et al., 2010; Wada et al., 2010).

In this context of global water scarcity and food security concerns, water footprinting is emerging as an important sustainability indicator in the agricultural and food sectors. There are different alternative methodologies in use alongside ongoing efforts to develop a standard in water footprinting. Water footprints can focus on different goals, such as water quantity or quality. Meanwhile, different tools exist to understand and account for water use along the supply chains and the risks related to it.

This guide has been developed at the request of the 45 IDF member countries, representing approximately 75% of the world's milk production. It has become evident to all concerned that the wide range of figures resulting from the differing methodologies and data is leading to inconsistent results, incongruent interpretation, uncertainty in decision-making and communication challenges. This poses a real danger of confusion and contradiction, which in turn could create a false impression that the industry is failing to engage actively with the issues of water consumption and water quality degradation.

1.2. Purpose of the IDF work on industry guidelines

IDF's goal in developing industry guidelines is to:

- Increase understanding about the concept of water footprint assessment
- Provide transparency about a product's water profile within its life cycle to enable monitoring, quantification and evaluation of the potential environmental impacts related to water use from cradle to the manufacturing gate exit, both in terms of quantity and quality
- Orient the identification of "hotspots" (areas targeted for consumption reduction)
- Enable the establishment of an indicator that can be used to measure progress on the actions taken to improve efficiency

1.3. Building international dairy guidance with other organizations

Different water accounting and impact methodologies have emerged over the last few years, and it is important to note that these are not mutually exclusive, although there is some overlap. From the outset, the IDF has been committed to reviewing existing standardization work and collaborating with organizations that are already involved in improving the standardization of life cycle assessment (LCA) methodology. Where a suitable model is already in existence, this has been used.

Since 2007, the Water Use in LCA (WULCA) working group, as part of the UNEP/SETAC Life Cycle Initiative, has been working on a framework that facilitates parallel use of different impact characterization methods. The result of its efforts is detailed on its website (http://www.wulca-waterlca.org/) and partially described further in this document.

The International Organization for Standardization (ISO) has published international guidelines for life cycle assessment: ISO 14040:2006 (ISO, 2006a) provides an important basis for framework and principles, and ISO 14044:2006 (ISO, 2006b) provides requirements and guidelines. The ISO standard *Water footprint – principles, requirements and guidance* (ISO 14046:2014) was approved in February 2014 (ISO, 2014) and the IDF was engaged in the processes where practicable.

Ultimately, the IDF work on sector-specific water assessment will be a major contribution to the FAO-led multi-stakeholder partnership on the environmental benchmarking of livestock supply chains (Livestock Environmental Assessment and Performance Partnership, LEAP [LEAP, 2015]). Through LEAP, international institutions, governments, NGOs and livestock private sector organizations (including IDF) are mutually developing science-based methods and guidelines on quantification of environmental performance, addressing greenhouse gas emissions, feed and biodiversity. This project started in July 2012 as a three-year initiative and, after meeting its goals, has been extended for another three years (i.e. LEAP+) to develop guidance in other areas such as water and nutrient cycling. The partnership will also enable the IDF to promote and improve its existing expertise in the area of life cycle assessment. IDF guidelines will continue to be working documents and will be adapted according to relevant international standards adopted in the future.

1.4. Who should use this guide?

The guide has been developed foremost for use by the dairy farming and dairy manufacturing sector, and for all those who are interested in defining a water footprint for their production systems and products using an LCA approach, trying to drive a change for better water use efficiency. For this, users of the guide will find directions on how to obtain the level of detail required for carrying out small-scale assessments.

The IDF guide is also designed to serve as a tool for policy makers when making policy decisions relating to water use within livestock production. It provides guidance on performing LCA at national or regional level in order to make broad assessments.

2 WATER FOOTPRINT ASSESSMENT AND LCA

2.1. The basics

A **product water footprint** assessment is usually based on **life cycle assessment (LCA)** methodology, incorporating both direct and indirect water use. LCA was originally used to analyse industrial process chains, but has been adapted over the past 20 years to assess the environmental impacts of agriculture. To date, it has mainly been employed in arable agriculture and less in livestock farming. The LCA method systematically analyses production systems to account for all inputs and outputs for a specific product and production system within a specified **system boundary**. The system boundary is largely dependent on the **goal** of the study. The reference unit that denotes the useful output is known as the **functional unit** and has a defined quantity and quality, for example a litre of milk of a defined fat and protein content.

The application of LCA to agricultural systems is often complex because, in addition to the main product, there are usually **co-products** created, such as meat, energy, etc. This requires appropriate partitioning of environmental impacts to each product from the system. Partitioning is based on an **allocation** rule, which can be based on different criteria such as value, product properties or system expansion.

Calculation of the water footprint of a product using LCA methodology should be based on the ISO 14000 series, specifically ISO 14040, ISO 14044 and ISO 14046. To conform with ISO 14046 and to address impacts on both water quantity and quality, the assessment should take into consideration **water consumption** and **water degradation**.

A decision to calculate the water footprint of a product is a conscious decision to focus on one environmental issue at a time. Other environmental impacts such as greenhouse gas emissions or land use should also be taken into consideration, when possible, in order to address the environmental impact of the global dairy sector in a holistic manner.

2.2. The challenges of water footprinting: a compromise

There are many challenges in calculating a water footprint. To date, there have been a variety of LCA studies and various water footprint studies investigating and evaluating water consumption from milk production (e.g. Haas et al., 2000). However, comparison between different studies is difficult when terminology and boundaries vary, as well as impact assessment methods. Therefore, it is difficult to identify whether a benefit really exists or only appears to exist because of a different method of calculation (Basset-Mens et al., 2009; Flysjö, 2011; Zonderland-Thomassen and Ledgard, 2012).

The main challenge is to reach a compromise between the following:

- A global approach, which is needed for environmental footprint statements, benchmarking and reporting to stakeholders to help policy makers. Comparability between studies is crucial.
- A local approach, which is essential to account for geographical and temporal relevance and to improve water use efficiency at the farm level (i.e. all activities regarding milk production carried out on- and off-farm should be taken into account, including feed production). This is only possible if local and detailed catchment-specific data or models are used.

The local approach is much more data and time consuming and so cannot be widely used at present. However, it is essential to be aware of the limitations of global approaches and to investigate, even minimally, at the local level before making any conclusions. To help meet this challenge, this guide proposes a tiered approach, where Tier 1 is a global approach and Tiers 2 and 3 are more local approaches.

The water footprint for milk and dairy products is typically dominated by the agricultural stage. This is why it is crucial to consider the variables in primary milk production that can affect the water footprint outcome, and to have a common approach for allocating the environmental burden from raw milk production between products such as milk, cream, cheese and butter, irrespective of the farm, system, country or even region.

Dairy production is a complex process that relies on a broad range of inputs, and there are a variety of production practices. Therefore, the task of conducting a water footprint analysis should involve stakeholders representing the range of dairy production practices and related sectors for the given study. Their participation improves data quality as well as its dissemination.

2.3. The steps in a water footprint assessment

As indicated in ISO standard 14046, a water footprint assessment consists of (Figure 1):

- Goal and scope definition
- Collection of data and water footprint inventory analysis
- Water footprint impact assessment
- Interpretation

If water is only being inventoried, then the impact assessment stage may be omitted. Use of the term “water footprint” alone can lead to confusion. Thus, in ISO 14046 and in this guide the term is only used when it is the result of an impact assessment.

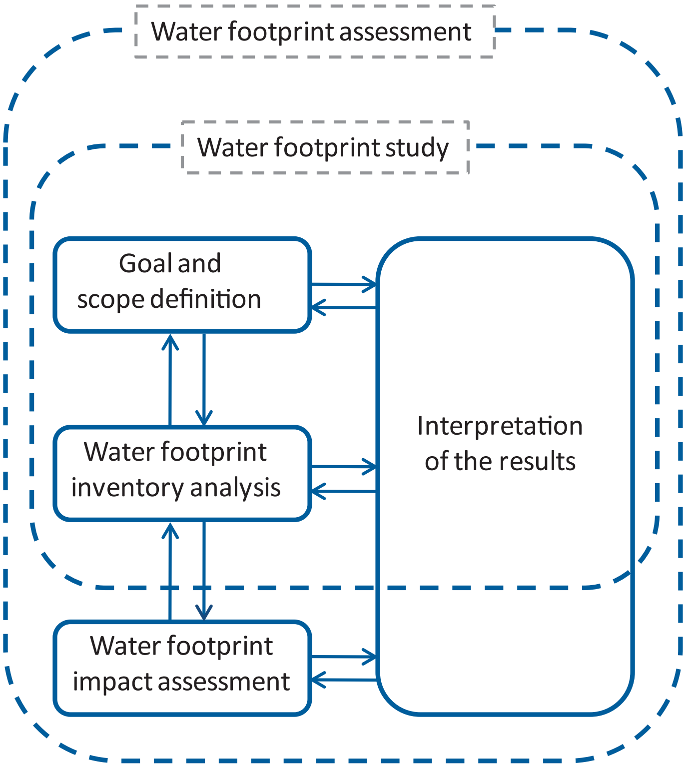

Figure 1: Phases of water footprint assessment (ISO 14046)

2.4. Setting the goal, scope and boundaries

The first step in the process of water footprint assessment is to be clear about the goal of the project. Knowing the goal helps to identify what is needed to conduct the analysis. Some questions to be answered here are: What are the activities and processes that contribute to the chosen product's life cycle (mapping the process)? What has to be measured (defining the system boundaries) and why? Who is the intended audience? Are the results to be used in public comparisons, to help policy makers in their decisions or to attain better water use efficiency in a dairy production farm?

Figure 2 shows a typical business-to-business or "cradle-to-gate" model, as described in ISO 14040 (ISO, 2006a). If only part of the process is being studied, for example milk production to the farm gate, then this process would be shortened accordingly.

2.5. Defining the process

The standard PAS 2050 (BSI, 2008; BSI, 2011) explains that to build a process map (flow chart) of a product's lifecycle (see Figure 2), the following stages should take place:

- Define where the process being studied starts and finishes
- Define the functional unit
- List all the activities involved in the process
- Reflect on what might have been missed
- Identify any co-products or by-products
- List all inputs and their inputs from origination (e.g. fertilizer used to grow feed for cow nutrition)

This provides a framework that helps to set the goal, scope and boundaries of the study.

It is also important to define the **functional unit** that will be the subject of the analysis, and to make a decision about which of two possible approaches will be adopted for modelling: **attributional** or **consequential** (see also IDF, 2015). Attributional assessments focus on describing the environmentally relevant physical flows to and from the product or process based on the current situation. By contrast, consequential assessments predict and describe how relevant environmental flows would change in response to, for example, changes in demand. The attributional approach is suggested in this guide because it more readily lends itself to consistency across studies.

Temporal, geographical and technological coverage should be stated as well as how representative these are for the study (i.e. water footprint data for milk produced in the USA cannot be seen as representative for African conditions, since the production systems are totally different).

- Geographical coverage has to be defined according to the scope of the water footprint study and the scale of the environmental impact assessment. If water footprint assessments are undertaken at the local scale, activities that are located in remote areas should be kept separate when selecting the activities to be included under the system boundaries.

- Temporal coverage should account for the temporal variability associated with all processes of water use and water consumption. For agricultural products it is important to have at least one year's average data so that seasonal variations during the year are accounted for. It is preferable to have data from multiple years to account for inter-annual variation.

- Technological coverage refers to, for example, whether the data used are representative for a modern or older dairy, a large- or small-scale dairy, etc.

An additional point to define in the scope of the study is whether the water footprint assessment will be **comprehensive** or **non-comprehensive**, that is, whether it will account only for water quantity or will also include one or several of the different categories of water quality (i.e. eutrophication, acidification, ecotoxicity, human toxicity and thermal pollution).

➢ In conformance with ISO 14046, the recommendation of this guide is to perform a comprehensive analysis and assessment that evaluates both types of impacts. Given the complexity of water footprint assessment, details on the study of environmental impacts of **consumptive water use** (affecting water quantity) and **degradative water use** (affecting water quality) are provided separately throughout this guide, with the purpose of combining both results later. **Single indicators do exist that include consumptive and degradative aspects as a whole (Ridoutt and Pfister, 2013), but these are not recommended in this guide.**

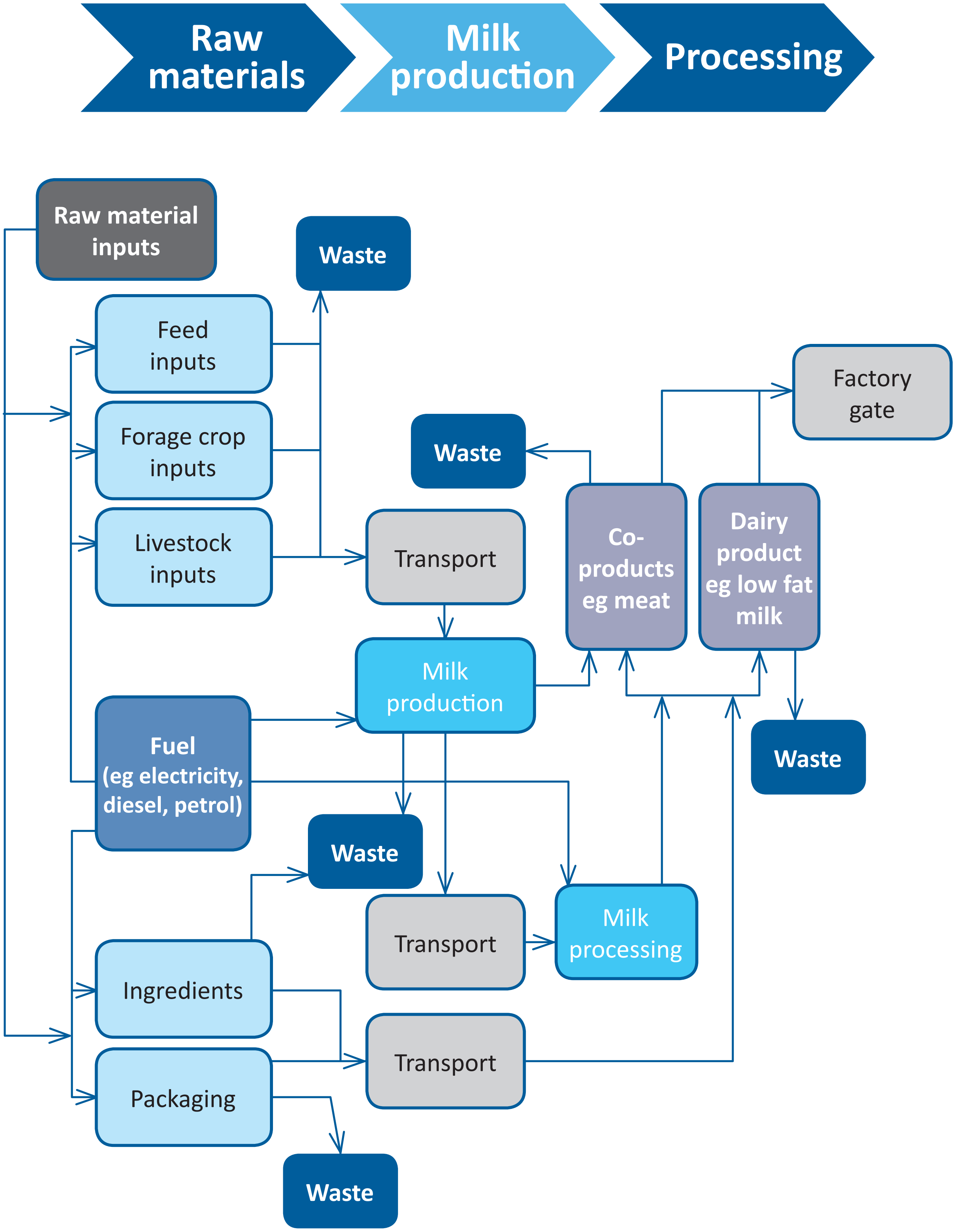

Figure 2: The process for milk production, then dairy processing, starts at the creation of farm inputs and stops at the factory gate exit. Example: Milk production with low fat milk as an end product. The system boundaries extend from the input of raw materials to the factory gate exit

2.6. The functional unit

2.6.1. Farming

If a study is conducted on-farm, the **functional unit** is one kilogramme of **fat- and protein-corrected milk** (FPCM), at the farm gate, in the country in which the analysis takes place.

Using FPCM as the basis for farm comparisons assures a fair comparison between farms with different breeds or feed regimes. FPCM is calculated by multiplying the milk production by the ratio of the energy content of a specific farm's (or region's) milk to the energy content of standard milk with 4% fat and 3.3% true protein content.

FPCM (kg/year) = Production (kg/year) × [0.1226×Fat% + 0.0776×True Protein% + 0.2534]

If a different milk composition is needed for the standard milk, the energy equation (see also Appendix 11.1 of IDF, 2015) can be used to calculate the new standard milk energy, and then used to recalculate the coefficients for the FPCM equation. Lactose content is essentially a constant 4.85% of milk.

2.6.2. Processing

At the processing gate, the recommended functional unit is one kilogramme of product, with *x*% fat and *y*% protein, packaged at dairy factory gate, ready to be distributed in the country in which the analysis takes place.

3 WATER FOOTPRINT INVENTORY: COLLECTION OF DATA

This phase involves **data collection** and **modelling** of the product (e.g. milk, cheese) system, as well as the description and verification of data. Values related to the different impacts are summed across the temporal and geographical coverage of the study and related to the functional unit.

3.1. Data to be collected

The following data related to water shall be considered for data collection (ISO 14046):

For assessing the environmental impacts of consumptive water use (where consumptive water use is water removed from available supplies without return to a water resource system):

- Quantities of water used (including water withdrawal and release)
- Types of water sources used (including for water withdrawal and water receiving body)
- Forms of water use (irrigation, storage)
- Changes in drainage, stream flow, groundwater flow or water evaporation that arise from land use change, land management activities and other forms of water interception (where relevant to the scope and boundary of the study)
- Locations of water use (including for water withdrawal and release) that are required to determine any related environmental condition indicator of the area where the water use takes place
- Seasonal changes in water flows, water withdrawal and release, when relevant
- Temporal aspects of water use, including, if relevant, timing of water use and length of water storage

Source: ISO 14046

According to ISO 14046, the total flow of evapotranspiration from a land-based production system is not considered to be crucial for calculation at the inventory level (also, at present there is a gap in available methods). Although reference values can be calculated and the difference in evapotranspiration assessed as water consumption (Nuñez et al., 2013), the uncertainties linked to the methodology are still too high.

For assessing the impacts of degradative water use, data describing water quality should also be collected:

- Quality of water used from the different types of water resources
- Emissions to air, water and soil with impact on water quality
- Locations of water use influencing water quality
- Seasonal changes in water quality

Source: ISO 14046

According to this, for dairy systems the following data should be included (see Figure 3):

- Farm level assessment of consumptive freshwater use
  - o On farm:
    - Freshwater (rivers, groundwater) required for crop and roughage cultivation (irrigation water)[1]
    - Freshwater required for cleaning the dairy parlour and collecting yard
    - Freshwater required for drinking by the animals, which depends on the ration (cows on a dry diet drink more water than those on pasture)
    - Manure management
    - Freshwater released at the farm
    - Respiratory vapour losses from animals
    - Capital and machineries are excluded because of their small contribution
  - o Farm inputs:
    - Freshwater use during production of concentrate and forage, processing at the feed mill and transportation
    - Freshwater use in the production of energy, pesticides, fertilizers, seeds and refrigerants and in their transportation
  - o Farm outputs:
    - Water in milk
    - Water in sold animals
    - Water in sold manure
- Farm level assessment of degradative freshwater use
    - Quality and volume of water released from the production of forage and crops on the farm
    - Quality of water released from the production processes for energy, pesticides, fertilizers, seeds and refrigerants and from their transportation

1 Where irrigation of crops and pastures occurs, this will usually be the most significant consumptive water use (care should therefore be taken to obtain the highest quality data with respect to these inputs).

- Emissions to air and soil with a potential for water degradation (e.g. acidification from ammonia and combustion emissions of SO_2 or eutrophication from nitrate leaching and/or phosphorus losses) are also included (based on ISO 14046); this targets all soil amendments for feed production, as well as emissions to air from combustion processes
- If manure is contained in a tank-less lagoon, nutrient leaching from the lagoon should also be estimated

A list of technical data needed at the dairy farm level is proposed in Appendix I.

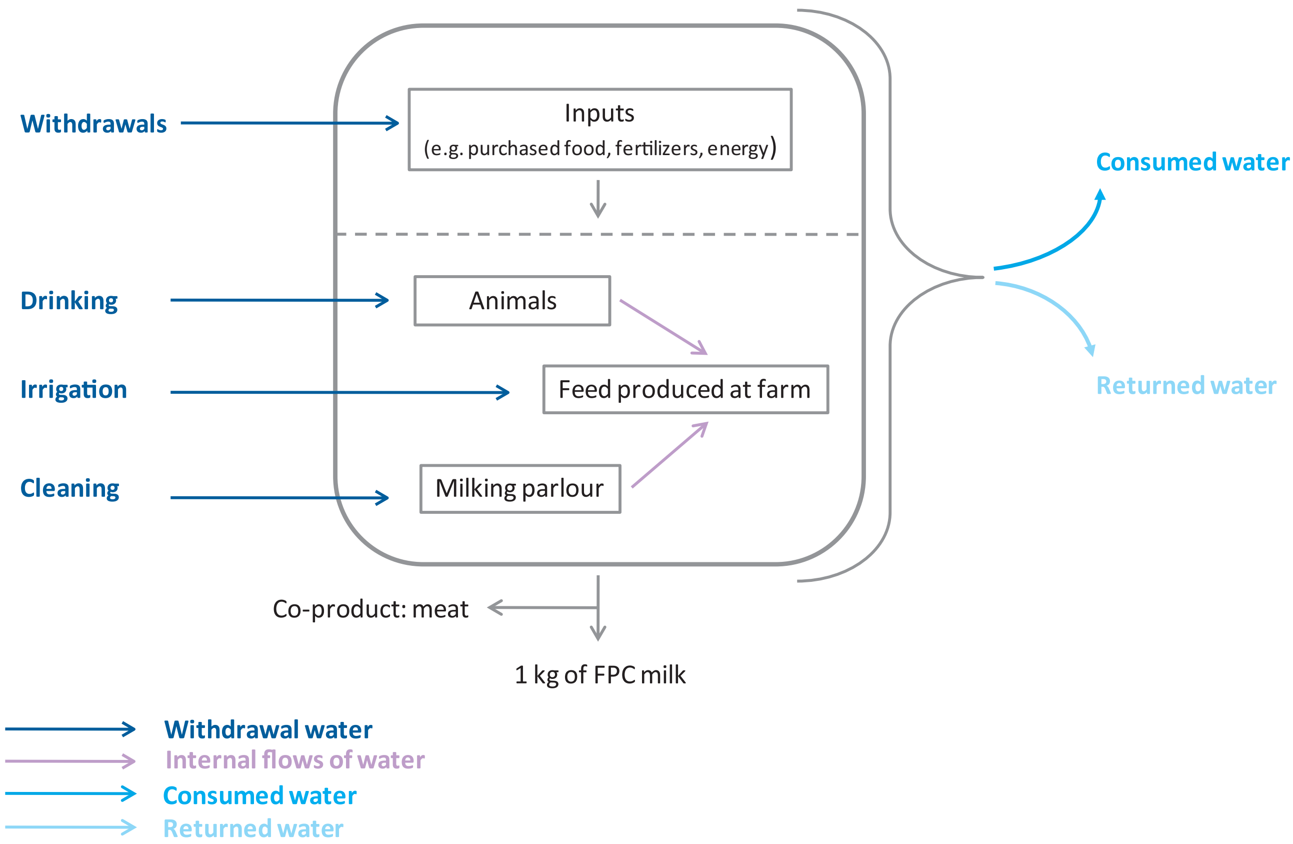

Figure 3: Physical flows of water at the dairy farm level (from Gac et al., 2012)

- Processing level assessment

Any post-farm gate water footprint assessment should be conducted following the guidance of the ISO standard on water footprint (ISO 14046), as the procedure for calculating a water footprint for milk processing is very similar to that for any other manufactured product. As stated previously, the water footprint of milk and dairy products is typically dominated by the agricultural stage, which is why the IDF has chosen to focus on the farm level in this first version of the guide. For specific guidance at the processing level, see ISO 14046 (ISO, 2014).

3.2. Data quality

One of the crucial issues in LCA calculations is transparency and reporting of the data used in the study. Ideally, the study should be reported in such a way that it allows an independent practitioner to reproduce the results.

It should be clearly stated whether primary data (collected), which are preferred, or secondary data (e.g. database, article, report) are used, and from what source the data are taken (e.g. the reference, company, or website the data is collected from, or from which database, article or report). The temporal[2], geographical[3] and technological[4] coverage should be stated as well as how representative[5] these are for the study.

The completeness of the study should also be clearly stated; for example, if some major items are omitted, such as capital goods, this should be made clear. Additionally, the methodology and level of detail throughout the study should be consistent.

Finally, the variation[6] and uncertainty[7] of data should be estimated, which could be done quantitatively through sensitivity analysis or qualitatively through discussion (e.g. with stakeholders).

- The IDF recommends that data sourcing and utilization are aligned with ISO 14044, which should be referred to for further details.

3.3. Data and models

3.3.1. Consumptive water use

The AQUASTAT database and CROPWAT (FAO calculation tool) can be used to prepare a first estimate of consumptive water use for feed crops. If irrigation is an important contribution to the water footprint, efforts should be made to confirm the regional sourcing of the crops and the relevant irrigation statistics for such regions and crops.

For the water footprint of electricity production, Pfister et al. (2011) provide average values of footprints for country-specific grid mixes, as well as footprints specific for different electricity production technologies.

2 Average data for a longer period or data from a specific year (for agricultural products, it is important to have at least one year's average data so that seasonal variations during the year are accounted for) and whether this period is representative for the study.

3 Whether the data are representative locally, nationally or, for example, for European conditions.

4 For example, whether the data used are representative for a modern or older dairy, a large- or small-scale dairy, etc.

5 The data used should obviously be relevant for the study (i.e. carbon footprint data for milk produced in the USA cannot be seen as representative for African countries because the production systems are totally different).

6 Emissions of, for example, N_2O are known to have large variations, both in time and space (between places). Variations can also result from differences between production systems.

7 The precision of data can often vary; for example, feed intake can be difficult to estimate, therefore, it is important to conduct a sensitivity analysis for crucial parameters, especially those for which it is difficult to obtain a precise estimate.

Relevant information about water quantity and water sources related to the production of material inputs at the farm (such as fertilizers) can be found in various databases, including the Quantis Water Database and ecoinvent 3.0.

3.3.2. Degradative water use

Different tools can be used to estimate the emissions to the environment and how they affect water quality. As with any assessment, a compromise must be made between ease and precision when choosing between the accessibility and complexity of the models available.

The models presented in Table 1 target the main pressures with a potential impact on water quality that result from fertilizers and pesticides applied on fields. More comprehensive modelling systems, such as the integrated farm system model (IFSM)(Rotz et al., 2012), can be used provided that all the emissions listed in Table 1 are included.

- ➢ The IDF recommends all the methods cited in Table 1 for estimating emissions that affect water quality, but **suggests using those at Tier 2 or 3** when possible.

Table 1: Models for targeting the main pressures with potential impact on water quality caused by nutrient surpluses and/or application of fungicides, herbicides or pesticides

Emissions	Model	Characteristics
Ammonia (NH_3) Tier 1	EMEP/CORINAIR (EEA, 2013)	Fertilizer- and manure-specific
Ammonia (NH_3) Tier 2	More specific models (e.g. Sheppard et al., 2010)	Models taking into account the soil and climatic conditions, such as that of Sheppard et al. (2010), developed in a Canadian context
Nitrates (NO_3) Tier 2	SQCB-NO_3 model, as per Nemecek and Schnetzer (2012)	Uses fertilizer concentrations, precipitation and irrigation statistics, clay content, rooting depth and plant needs. Values are suggested for all parameters except fertilizer use.
Nitrates (NO_3) Tier 3	Site-specific models (e.g. DeNitrification-DeComposition)	Requires farm-gate nutrient balance for individual farms, combined with data on soil types and meteorological data. The FAO LEAP partnership is currently developing a quantitative framework for the assessment of nutrient use efficiency along livestock supply chains. Methodologies for quantification are expected to become available between 2016 and 2017.
Phosphate (PO_4) Tier 1	As per Nemecek and Kägi (2007), based on the SALCA-P model (Prasuhn, 2006) for both run-off and leaching	Uses fertilizer concentration

Phosphorus Tier 2	As per Nemecek and Kägi (2007), based on the SALCA-P model (Prasuhn, 2006)	The model takes into account soil erosion, surface run-off and drainage losses to surface water and leaching to groundwater. Values are suggested for each parameter.
Phosphate (PO_4) Tier 3	Site-specific models	Requires farm-gate nutrient balance for individual farms, combined with data on soil types and meteorological data. The FAO LEAP partnership is currently developing a quantitative framework for the assessment of nutrient use efficiency along livestock supply chains. Methodologies for quantification are expected to become available between 2016 and 2017.
Pesticides Tier 1	Based on Fantke et al. (2011)	Uses concentration of active ingredient applied, and assumes that 16.5% is emitted to air while the balance is emitted to soils. Toxicity models then assume partial emissions to water
Pesticides Tier 2	PestLCI model (Dijkman et al. 2012)	Requires a lot of local climate data

3.4. Allocation

Allocation is necessary when systems or processes produce multiple products or services (co-products) and when other options (e.g. expansion of system boundaries) are not possible. Allocation is used to assign the inputs and outputs of a process to the function that is being studied. Guidance on allocation procedures used in the water footprint assessment of products and processes should be based on that given in ISO 14044 (and ISO 14046).

There are various ways to handle co-products, with some methods being more pragmatic and others more scientific, but there is no single, common or established method. The allocation procedure described by ISO 14044 is as follows:

Step 1: Wherever possible, allocation should be avoided by either:

- Dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes
- Expanding the product system (known as system expansion) to include the additional functions related to the co-products

Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them (i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system).

Step 3: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

Looking at the whole life cycle of milk and dairy products from farm to manufacturing gate exit, there are several processes that involve multiple co-products (see also *A common carbon footprint approach for the dairy sector. The IDF guide to standard life cycle assessment methodology*; IDF, 2015):

- Production of feed (e.g. soy meal or soy oil)
- Production of milk and meat on-farm (where meat and calves are a by-product, and also manure if it is exported from the farm)
- Manufacture of dairy products at the processing site
- Energy generation (e.g. biogas production on-farm or electricity produced at the dairy manufacturing site, where surplus electricity can be exported to the grid)

Allocation principles and procedures must also be applied to reuse and recycling of water. In this case, specific procedures should be applied because the same water – with similar or different properties – can be used in more than one product system. Specific guidance can be obtained from ISO 14046.

Water use at the farm for cleaning milking equipment is mostly attributable to dairy production, as is water used in relation to milk transportation and transformation; thus, no allocation is necessary in this case. On the other hand, irrigation water and water use upstream of the farm are attributable to both milk and meat production, with the same methodological logic used in developing the physical causality allocation factor (IDF, 2015).

3.5. Assumptions

As in any LCA model, it is necessary to make a number of assumptions in order to fill the data gaps inherent in a complete system, allowing the model to account for quantities that cannot be easily measured. This is especially true when performing a water balance, in which every input and output of water should be accounted for, even when these flows are not measurable.

Assumptions are also necessary to account for indirect water flows associated with all materials and energy inputs of the system. However, because these flows are accounted for using databases and published data, certain assumptions have already been made and accepted. These can be left as such, with an appropriate analysis of the uncertainties. That said, in exceptional cases where indirect water flows are major contributors to the water footprint inventory, such as those associated with energy inputs in a non-irrigated system, care should be taken to ensure that these are relevant (e.g. that the energy footprint is representative of the electrical grid mix provided in the region assessed).

Key assumptions are necessary for modelling the fates of irrigation water (percentage evaporated) and fertilizers (percentage leached or as run-off) and affect both the quantity and quality aspects of the water footprint assessment. Furthermore, an in-depth assessment of the source (surface or groundwater) of water withdrawal must assume that a fraction is returned to groundwater as opposed to surface water.

During irrigation, only a very small fraction of the irrigation water is actually absorbed by the plant, because the largest fraction normally evaporates. The irrigation efficiency is the ratio of water volume that is beneficially used (absorbed by the plant or stored in the soil) to the total volume of irrigation water withdrawal. This ratio (often expressed as a percentage) mainly depends on the type of irrigation system in use (e.g. flood, sprinkler or drip systems)[8]. Knowing this, irrigation efficiency values can be obtained from peer-reviewed literature. If no specific data on the irrigation technology is available, irrigation efficiency can be estimated for a geographical area with the help of published data (e.g. irrigation consumptive water use as a percentage of reported agricultural water withdrawals, as described by Siebert et al., 2010). In many cases, the fate of surplus irrigation water after evaporation is unknown and this fraction should therefore be accounted for in the water footprint assessment inventory. Only if there is evidence can it be assumed that the balance returns to the water body from which the water was extracted.

Estimates of contamination from fertilizers is more complex and can make use of different models of different precision, chosen on the basis of the resolution of the study and the information available. These methods are detailed in Section 6.

8 Common estimates are 30% for flood, 60% for sprinkler and 90% for drip systems.

4 WATER FOOTPRINT IMPACT ASSESSMENT

4.1. Levels of assessment

Within the framework of a water footprint assessment, the impacts of water consumption and degradation should be assessed.

There can be three levels of assessment, which each bring valuable information, and an optional communication step to promote use of the results. These steps are illustrated in Figure 4 (from Kounina et al., 2013 and Bayart et al., 2010).

As with any footprint assessment, assessing the inventory (entering and exiting flows) provides a general understanding of the relevance of water sources and uses, both direct and indirect, to see where reductions are possible. Subsequently, two levels of water footprint impact assessment can be used to understand the local dimension of the inventory with respect to water scarcity and degradation:

1. Midpoint assessment (uses indicators at an intermediary point in the water use/degradation cause–effect chain)

2. Endpoint assessment (provides specific indicators for potential damage to human health, ecosystem quality and resources)

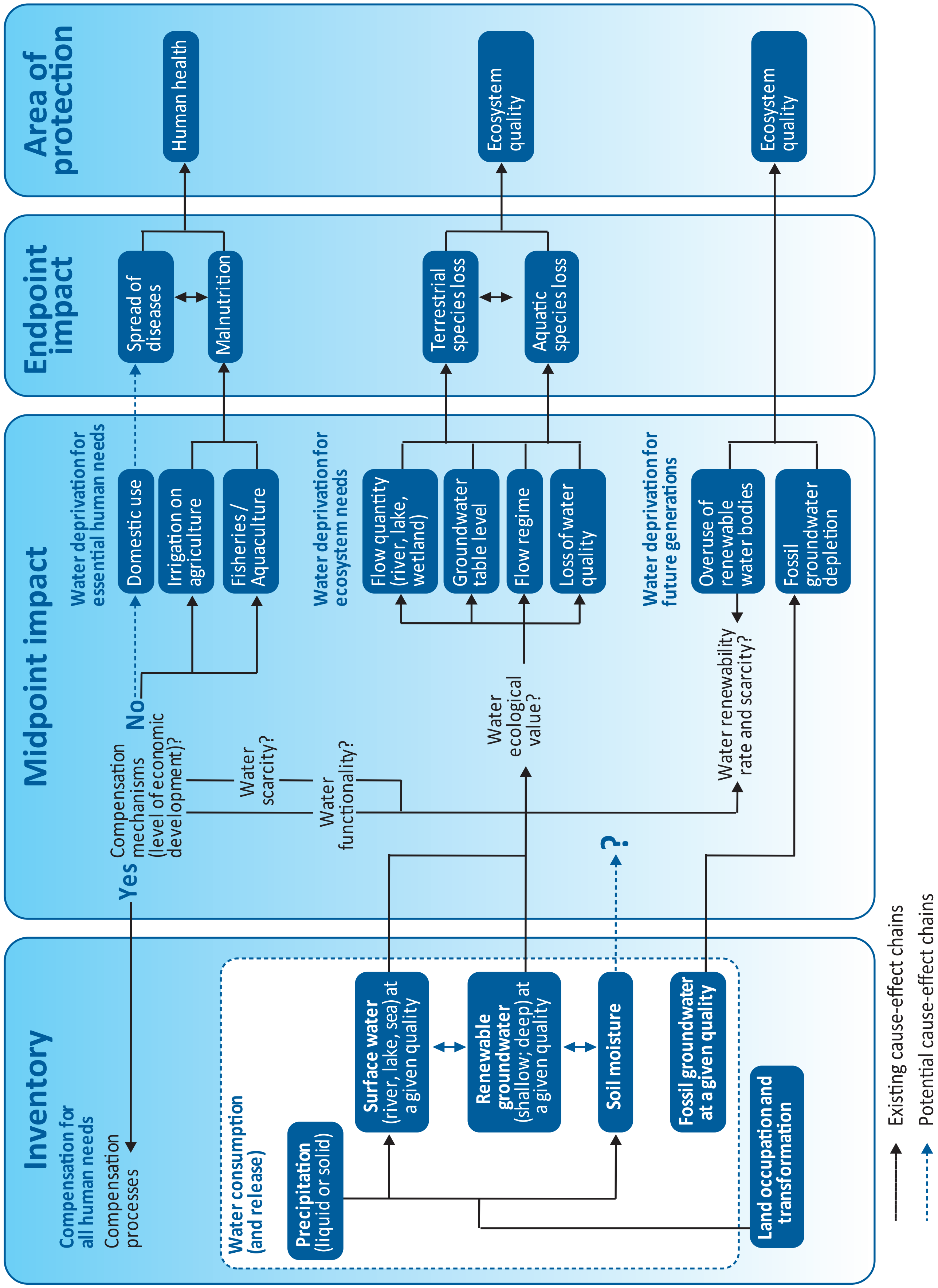

Figure 4: Cause–effect chains leading from the inventory to the areas of protection of human health, ecosystem quality and resources (adapted from Bayart et al. 2010 and Kounina et al. 2013)

Unlike a carbon footprint, the impact of changes to the water balance are localized, although a supply chain can be global, thereby expanding the overall impact to a much wider zone. Based on local conditions at the point of withdrawal or contamination, impacts on ecosystems and human health can vary greatly. This is a key point to remember during the assessment and its interpretation.

4.2. Scale of the impact assessment at the farm

From cradle to farm gate, the (potential) impact of dairy production and processing on water quality and quantity can be quantified at a range of scales: farm, catchment and intermediate (see Appendix II for more information on these scales). Because the agriculture stage dominates, the simplest scale for conducting a water footprint assessment is the farm scale. However, impact assessments are primarily carried out at the catchment scale, which covers the extent of land sharing a common drainage basin and is the scale at which agriculture impacts water quality and scarcity. Most water monitoring and reporting programs operate at the catchment scale (EPA, 2016); however, modelling an activity for the purpose of calculating emissions is done at the farm scale. Assessments of water quality can be also performed at an intermediate scale to account for the transformation processes taking place between the sources of inputs and the receiving water bodies (Wall et al., 2011; Shortle et al., 2013).

- Although water quality monitoring at the catchment scale is more representative of actual change, it offers too many variables (as does the intermediate scale) to allow distinct profiling of dairy farming activities. As a result, **the IDF recommends assessment of potential impacts of farm practices at the farm scale**, despite its limitations.

5 ENVIRONMENTAL IMPACT OF CONSUMPTIVE WATER USE

The impacts of water consumption are local. They may involve increased scarcity, reduced river flows and lower groundwater levels, thereby affecting ecosystems and perhaps even human health through unavailability in areas where alternatives are not affordable or easily available.

> Environmental relevance must be taken into consideration if water footprints are to inform decision making and policy development. Water use in a region of abundance does not have the same potential to impact human wellbeing and ecosystem health as water use in a region of water scarcity. The need to reduce humanity's water footprint does not arise from an absolute spatial and temporal shortage of freshwater in the world. It is the result of the current pattern of freshwater use, which is greatly skewed toward highly stressed watersheds. Environmental relevance is the key to understanding water footprints. This issue is why the international water footprint standard, in development by the ISO, includes this relevance[9] as a core principal.
>
> Source: Ridoutt et al., 2012

5.1. Impact assessment

A series of recent models allow the characterization of specific cause-and-effect chains with impact on ecosystems, such as the consumption of river waters, groundwater, the release of hot cooling water, etc. These are helpful when the degree of detail (using a database with a fine resolution) allows characterization of the different types of freshwater, as well as the destination of water used in cooling processes. This can be interpreted as an in-depth assessment of the water inventory. The methodologies dealing with withdrawal and consumption are summarized in Figure 5, as per the review article by Kounina et al. (2013), describing the inventory and impact assessment of freshwater use potentially applicable in LCA. This review was used by the Water Use in LCA (WULCA) group (UNEP-SETAC Life Cycle Initiative) to identify the key elements for building a framework and establishing scientific consensus for an operational characterization method (Bayart et al., 2010).

9 Data and methods are selected such that they are appropriate for the water footprint assessment (ISO, 2014).

Figure 4 illustrates the different levels of interpretation along the cause-and-effect chain. The "cause" is assessed at inventory level, using databases and measurements. It is then translated into a benchmarked issue, called a midpoint (e.g. in carbon footprinting, where different greenhouse gases are converted to CO_2 equivalents). Finally, a link is made between this midpoint and its potential impacts on ecosystems, human health or resources, using a characterization factor to calculate the endpoint.

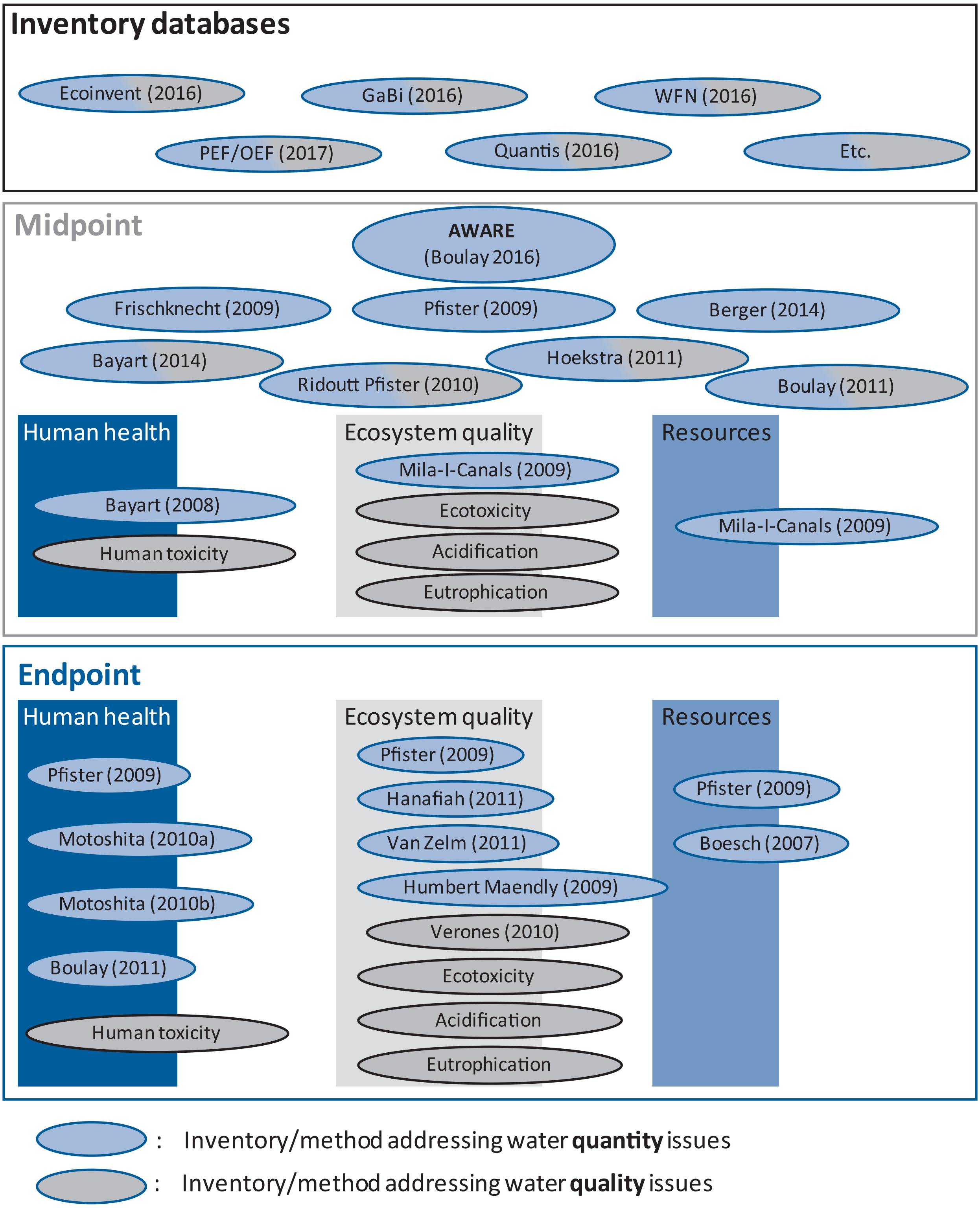

Figure 5: Three levels of interpretation of a water footprint (updated by Quantis from Kounina et al., 2013)

5.1.1. Endpoint methods

The article by Pfister et al. (2009) provides characterization factors that are regionalized and broadly estimates endpoint impacts in all three areas of protection in the LCA context: human health, ecosystem quality and resources. It also provides, as one of several options (e.g. Boulay et al., 2011, Frischknecht et al. 2006), a regionalized index for water scarcity that can allow weighted comparison of the risk (midpoint impact) linked to water consumption in different locations.

When water source type is known (surface or underground water), it is possible to calculate the potential endpoint impacts on ecosystem quality caused by lowering levels of underground (Van Zelm et al., 2010; a Dutch model) and surface (Hanafiah et al., 2011; a global model) water. Groundwater and surface water impacts on wetlands have been specifically addressed by Verones et al. (2013a, b). In water-scarce ecosystems, withdrawal of consumptive water eventually reduces availability of water for terrestrial systems and, consequently, affects species diversity. Water consumption from surface water affects water flow, which in turn affects aquatic biodiversity. The endpoint for impact on ecosystem quality is usually expressed as the potentially disappearing fraction (PDF) of biodiversity in a square metre in a year (PDF/m^2 ×/year) for terrestrial systems and in a cubic metre in a year (PDF/m^3/year) for aquatic ecosystems.

Additionally, exhaustion of a water resource can be caused by using fossil groundwater from a deposit or by overusing water from a fund or flow. The damage induced can be estimated through a characterization factor for resource depletion for each country (Pfister et al., 2009). This characterization factor equals the aggregated value times the energy required to desalinate one litre of seawater and is therefore expressed in kilojoules per litre of water consumption. This characterization is of interest for practitioners performing a full LCA; however, the method is approximate and its impact does not characterize the actual depletion of non-renewable groundwater. The method is thus too limited to recommend its inclusion.

5.1.2. Midpoint methods

Midpoint methods, as described at the beginning of this section, serve to aggregate different inventory flows with an equivalence factor. With water, the underlying driver is that a litre withdrawn in a water-abundant country does not have the same impact as water withdrawn in a water-scarce country.

Scarcity indicators aim to give meaning to the comparison of water use in different areas in the world. Different methods have been published over the last ten years, each offering a variation on previous work. Other methods are available that look at a stress index rather than a scarcity index. A stress index aims at including both scarcity and quality factors into the comparison of watersheds. The two most referred to methods appear to be Veolia (2012) and Boulay et al. (2011). However, stakeholder adoption did not lead to many published cases or to critical evaluation of these methods.

Scarcity indices[10] such as the water stress index (WSI) of Pfister et al. (2009) are a logistic function of the total annual water use, using the withdrawal (or consumption, when using the method of Boulay et al., 2011) divided by total annual water availability. This value can be adjusted for seasonal variability in precipitation and flows in a watershed, a region or a country (Pfister et al. 2009) or to represent variability in quality (Boulay et al., 2011). With a value between 0.01 and 1, a WSI of 1 indicates a greatly stressed watershed, whereas low indexes are related to watersheds of low water scarcity[11].

➢ For its wide distribution and current popularity, as well as for the parallel availability and regional specificity of characterization factors in the three areas of protection (endpoints as shown in Figure 5), the IDF recommends use of the midpoint and endpoint factors developed by Pfister et al. (2009) in the assessment of the impacts of consumptive water use.

The indicator result for consumptive water use (CWU) is expressed in H_2O equivalents (H_2Oe) and is the result of multiplying each instance of water consumption (balance of water inputs and outputs, typically in cubic metres or litres) by a characterization factor defined by the local WSI divided by the global average WSI[12]:

$$\text{Indicator result for CWU } (H_2Oe) = \Sigma_i \, [CWU_i \times (WSI_i/WSI_{global})] \qquad \text{Equation 1}$$

The ratio (WSI_i/WSI_{global}) gives the inventoried volumes of water a more representative impact, as it increases the footprint in areas that are more water-scarce than- average, and diminishes the footprint in less water-scarce areas.

➢ In October 2015, The WULCA group managed to reach an international consensus on a new scarcity indicator for assessing potential user deprivation, which is a stress-based generic midpoint. The new indicator is called AWARE (Available WAter REmaining per area in a watershed). The Pellston workshop of UNEP SETAC Life Cycle Initiative on Life Cycle Impact Assessment (LCIA) chose AWARE as a consensus impact method. It was recommended as the interim method until more case studies have been conducted and published and no more unexplainable or unjustifiable issues have been identified.

➢ It is important to note that, unlike preceding scarcity indicators, the AWARE method uses a range of values between 0.1 and 100 (instead of 0.01–1). Therefore, results can vary greatly from values previously calculated or published using previous methods, although all refer to a litre-equivalent unit calculated using a water scarcity indicator.

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10 In this document, the IDF uses the term “water scarcity”, in alignment with ISO standard 14046, which is defined as the “extent to which demand for water compares to the replenishment of water in an area” (ISO, 2013). However, the term “water stress” is broadly used by experts when assessing the impact of water consumption/withdrawal.

11 A Google Earth layer with WSI data is available for download at: http://www.ifu.ethz.ch/ESD/downloads/EI99plus

12 For the WSI of Pfister et al. (2009) the global average consumption-weighted value is 0.602.

- **For these two reasons, the IDF recommends AWARE as an interim method until it is tested and validated with more agri-food case studies, and dairy case studies in different geographic locations.** The dairy sector can use the AWARE method in parallel with the midpoint and endpoint factors developed by Pfister (Pfister et al., 2009). The Pfister method remains the recommended method while waiting for the definitive validation and wider adoption of the AWARE indicator. The Pfister method helps provide benchmarks, if comparison is an objective.

The AWARE indicator describes the potential to deprive users (human and ecosystem), based on available water remaining after demand is met. Indicators are calculated at a sub-basin scale (also available at the country scale) and at a monthly scale (also available at the annual scale):

Water deprivation potential = water consumption x CF

Where CF = 1/availability – demand

Demand includes human and aquatic ecosystems. The value is normalized with the reference flow of the consumption-weighted world average. There is maximal value when demand is greater than availability (a value of 10 means that there is 10 times more unused water available in the region compared with the world average situation for water consumption).

CF is the inverse of unused water remaining (the more unused water available per area, the lower the potential to deprive other users.

AWARE is first calculated as the water availability minus the demand (humans and aquatic ecosystems) and is relative to the area (cubic metres of water per square metre per month), hence representing the area “virtually occupied” to cover the additional water consumption sustainably. In a second step, the value is normalized with the world average result and inverted, hence representing the relative value in comparison with the average cubic metres consumed in the world. The indicator is limited to a range from 0.1 to 100, with a value of 1 corresponding to the world average, and a value of 10, for example, representing a region where there is 10 times less available water remaining per area than the world average.

Information and data on this new indicator can be found at
http://wulca-waterlca.org/project.html.

6 ENVIRONMENTAL IMPACT OF DEGRADATIVE WATER USE

Above and beyond scarcity, it is equally important to evaluate water quality impacts such as those causing toxicity (ecological and human impacts), eutrophication, acidification and thermal pollution. Although these impacts all concern water quality, they can occur as a result of emissions to air and soil (such as combustion emissions of SO_2 causing aquatic acidification, and soil fertilizers causing eutrophication), as well as direct emissions to water bodies. In line with the current ISO 14046 standard, these emissions (to water and air) should be included in the scope of a comprehensive water footprint assessment to accurately model potential contamination in an integrated way.

6.1. Impact assessment: the pressure–pathway–receptor model

Pollution of water only arises when agricultural **pressures** (which can occur as a result of a specific incident or the accumulation of past pressures), after being partially transformed through **pathways**, end up in water **receptors** that are sensitive to the total resulting pressure (Haygarth et al., 2005; Schulte et al., 2006), thereby causing a concentration that exceeds either the ecological or human health thresholds. The pressure–pathway–receptor model (referred to as an emission–impact model in LCA terminology) justifies why loss of agricultural inputs to water bodies does not necessarily equate with pollution or impact on water quality. The model is explained in the following the sub-sections and illustrated in Figure 6.

6.1.1. Pressure factors

Pressures refer to local accumulations of potential pollutants that could be transported to water bodies (including groundwater and surface water) in the presence of transport vectors. Pressures can arise from, for example, nutrient surplus or application of fungicides, herbicides or pesticides. Pressures vary over time; for example, surplus nutrient application could increase the local pressure of nitrogen, but this pressure could ease during the year(s) as nitrogen is taken up by the crop(s). The amount of pressure that a farm or farming system exerts on the aquatic environment is largely a function of crop management, nutrient management (nutrient surplus, nutrient use efficiency) and herd or grazing management. A specific challenge for nutrient management in livestock systems is the efficient utilization of the nutrients in animal manures. In grazing systems, the deposition of nutrients (specifically nitrogen) by grazing animals results in a high degree of spatial variability in soil nitrogen concentrations, with concentrations in excess of grass requirements in urine patches (Hoekstra et al., 2007; Stark and Richards, 2008).

6.1.2. Pathway factors

Pathways are the transport routes or mechanisms that spatially connect areas of pressure with receptors (see below). Pathways include overland flow, interflow[13] and the infiltration/percolation and vertical transport (to groundwater) of excess rainfall. In a wider context, pathways can also include air (through volatilization or wind erosion) in the case of ammonia, which is subsequently re-deposited to surface waters and soils. Airborne pathways are specifically relevant for nitrogen and some pesticides, but of minor concern with respect to other nutrients.

At the local level, the nature of pathways depends primarily on soil properties and hydrology (which will determine overland versus vertical flow pathways)[14]. Local meteorological factors are also very important, specifically the level of excess (or net) precipitation (precipitation minus evapotranspiration)[15] and the rainfall intensity frequency distribution. Excess precipitation determines both the magnitude of the pathway and the “dilution” or concentration of the pressure (e.g. nutrient loss). As a result, higher levels of excess precipitation could impact either negatively or positively on water quality. On the one hand, high levels of excess rainfall provide larger or more pronounced loss pathways; on the other hand, high levels of excess rainfall can dilute the material that is lost (Schulte et al., 2006; Schulte et al., 2012 for a full review). The frequency distribution of rainfall intensity is important in that high-intensity rainfall events can result in infiltration-excess overland flow, even for soils that are not prone to overland flow in “normal” rainfall events (Schulte et al., 2006).

6.1.3. Receptors

Receptors are the recipient water bodies in agricultural catchments. These include groundwater, river/lake water bodies and estuarine water bodies. These water bodies have varying degrees of sensitivity to different inputs and losses from agricultural activities (e.g. the buffering capacity of water flowing on alkaline soils against acidification impact), sensitivity being a function of current and past stresses.

13 Lateral movement of water in the unsaturated zone of the soil that returns to the surface or enters a stream prior to becoming groundwater.

14 For example, stagnisols and gleysols are characterized by their low capacity for water infiltration, with overland flow as the resulting dominant pathway. At the other extreme, arenosols and podzols are freely draining, resulting in predominantly vertical pathways for excess rainfall and an absence of overland flow pathways.

15 Excess precipitation can be calculated using the FAO guidelines for computing crop evapotranspiration (Allen et al., 1998).

6.1.4. Impacts

The degree to which losses translate into impact or pollution, impacting on human health and/or the ecological functioning of aquatic ecosystems, is highly dependent on (i) local ecological conditions (pathways, ameliorating factors and receptors sensitivity) and (ii) environmental thresholds. Pressures generating losses that reach receptors might not result in pollution if the concentrations remain below the thresholds of the receptor bodies (for ecological and human health; see Figure 6).

Threshold values for concentrations of chemicals in drinking water have been set by the World Health Organization (WHO, 2011). In this context, it is important to consider variations, because concentrations can fluctuate considerably both spatially and temporally (Jordan et al., 2012).

With respect to the ecological sensitivity of the receptor to concentrations of nutrients and other substances, we need to take into account that different receptors show different responses. For example, the response of estuarine ecosystems to nitrogen and phosphorus differs from the response of river ecosystems, which in turn differs from the response of lacustrine ecosystems (EPA, 2001). Even within one ecosystem, species can display a wide range of sensitivity. Therefore, the degree to which losses translate into impact or pollution is highly dependent on local ecological conditions and thresholds. It is for this reason that water quality monitoring schemes and indeed (trans-)national policies aimed at protecting water quality are increasingly based on ecological rather than chemical indicators (e.g. EU Water Framework Directive; EU, 2000).

Ultimately, if the assessment is carried out at the catchment scale, loss of surplus nutrients and other farm inputs needs to be considered in the context of the land use and hydrology of the wider catchment that the farm is situated in. Concentrations of possible pollutants in the receiving water body are an aggregate of the concentrations in individual parts of the catchment, both spatially and temporally. In other words, losses from agriculture may be “diluted” by land use in the same catchment that is associated with lower loss rates. Inversely, losses from other human activities (e.g. from wastewater treatment plant outlets) could compound concentrations (e.g. of nutrients) and hence increase the risk of eutrophication (Jordan et al., 2012).

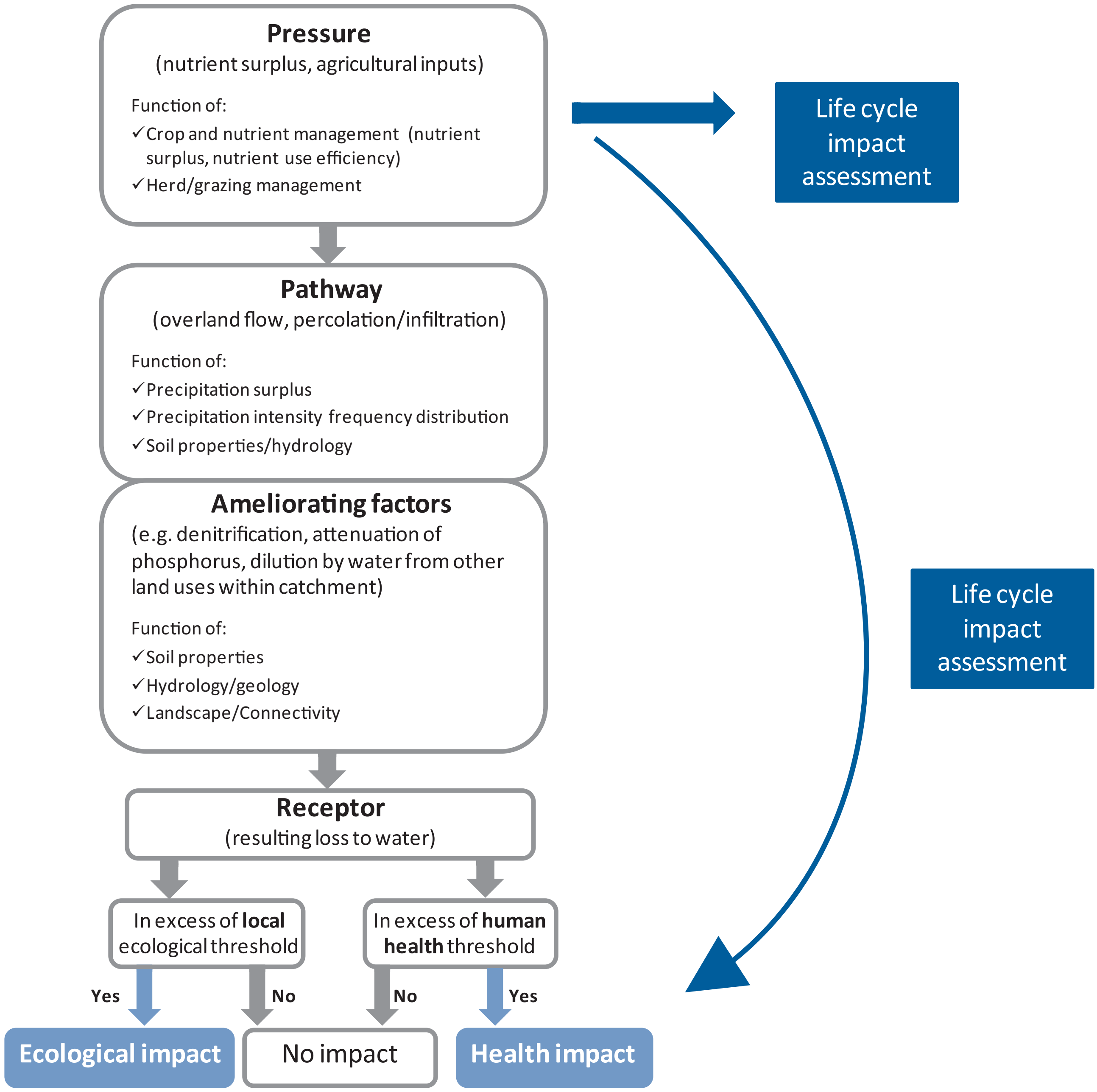

Figure 6: Conceptual framework for assessing the potential impact of livestock farming on aspects of water quality

The IDF recommends use of the pressure–pathway–receptor model for assessment of the impact of degradative water use. However, the quantification of pathways impacting at the intermediate scale is not recommended, given the potential high variability in the pathways (and the ameliorating processes). Thus, the recommendation is to focus on pressure factors as a first step. Pressures can be translated into potential impacts on ecosystem quality and human health through the use of LCA models. As a second step, to identify the levers of action more precisely and recommend mitigation action, it is advised that local tools following the pressure–pathway–receptor model are used. This is because, to gain a more complete understanding of the potential impacts in the study area, it is important to also consider the pathways that potentially exist and how they might be influenced by local conditions (while being aware of the difficulty of accurately defining pathways). Approaches other than the pressure–pathway–receptor model can be used, but the reasons driving that decision should be explicitly provided.

6.2. Conclusion

The method proposed in this guide represents a compromise between a global approach that is needed for environmental footprint statements, and a local approach that accounts for geographical and temporal relevance, and is essential for improving water use efficiency and water quality at the farm level (i.e. all activities regarding milk production carried out on- and off-farm should be taken into account, including feed production). It should be noted, however, that the high variability of local water conditions makes farm-level assessment difficult. This limitation should be taken into account in the interpretation of the results of any water footprint assessment.

- In conformance with ISO 14046, the recommendation of this guide is to perform a comprehensive analysis and assessment that separately evaluates both types of impacts: consumptive water use (affecting water quantity) and degradative water use (affecting water quality). The results should be provided separately. For consumptive water use, the recommendation is to use the midpoint and endpoint factors developed by Pfister et al. (2009). For degradative water use, the recommendation is to focus on pressures that can be translated into potential impacts through the use of the LCA models listed in Table 1. Promising new methods are emerging to improve these models, but they are not advanced enough at this stage to be cited in this first version of the guide.

- To better understand the impacts and identify levers of action at the farm level, the IDF recommends conducting a complementary study using local tools that can integrate details on local pathways and receptors.

7
CALCULATION EXAMPLES

7.1. Farm-level example

The case study at the farm level has been extracted from Ridoutt et al. (2010) for the production of 1 kg of skim milk powder in a conventional pastured-based farming system (supplemented by purchased hay and grain) in the region of South Gippsland in Victoria (Australia).

To create an inventory of consumptive freshwater use, the following steps were taken[16]:

- Inputs to dairy farming were modelled using data for six farms located within the supply catchment of the dairy. The data were independently collected as part of a larger farm benchmarking study in 2008–2009 (Gilmore et al., 2009). Minor inputs not included in the study (e.g. business services, veterinary services, agricultural chemicals) were modelled using other farm survey data (ABARE, 2010). To calculate the water use in the production of all these inputs to farming (Table 2), input–output data (Foran et al., 2005) and other LCA database sources were used. Allocation between co-products was conducted following an economic approach.

Table 2: Characterization of the skim milk powder system at the farm level

Variable	Value
Average farm grazing area (ha)	159
Average cropping area (ha)	98
Average number of milkers (head)	232
Annual milk production (L/head)	6 095
Electricity consumption (kWh/farm/year)	70 036
Diesel consumption (L/farm/year)	6750
Fertilizer use (tonnes/farm/year)	73
Purchased hay (tonnes/farm/year)	18
Purchased grain (tonnes/farm/ year)	330
Irrigation water use (ML/ha)	0
Dairy shed water use (L/head/day)	36
Drinking water requirements (L/head/day):	
Lactating cow	150
Heifer <1 year old	50
Heifer >1 year old	80
Bull	70

16 To consider other LCA impact categories such as eutrophication or ecotoxicity, additional emissions to freshwater from fertilizers or pesticides need to be taken into account.

- Data on water collected and used directly on-farm for livestock and dairy shed operations and the management and use of dairy shed wastewater were sourced from a survey (Callinan, 2010) and from consultation with local farming experts (Table 3). These data were used to quantify the change in drainage and stream flow as a result of on-farm collection and use of precipitation.

- The baseline situation was modelled using the equation of Zhang et al. (2001) relating evapotranspiration (ET) to precipitation (P) for grassed catchments (see equation below); the difference between P and ET was assumed to contribute to deep drainage and stream flow.

$$ET = [1 + (0.5 \times 1100/P)] / [1 + (0.5 \times 1100/P) + (P/1100)] \times P$$

Impact assessment

To assess the impact of consumptive water use, local characterization factors were taken from the water stress index (WSI) of Pfister et al. (2009) and used in relation to farm inputs. To calculate the water footprint, each instance of water use was multiplied by the relevant WSI and then summed across the product life cycle. The product water footprint was then normalized by dividing by the global average WSI and expressed in H_20 equivalents (H_2Oe, see Equation 1 in Section 5.1).

Results are presented in Table 3. The blue water consumption was 14.1 litres of water per litre of milk, with 83% occurring on-farm (animal drinking plus shed water use). In contrast, the water footprint was 1.9 litres of H_2Oe per litre of milk, meaning that the production of one litre of milk in Grippsland had the potential to contribute to freshwater scarcity equivalent to the direct consumption of 1.9 litres of water (at the global average WSI of 0.602). The water footprint was so low because the farms were located in a region of Australia with plentiful water and extremely low WSI (0.013).

Table 3: Volumetric blue water consumption (litres of water per litre of milk) and water footprint (litres of H_2Oe per litre of milk) at the farm gate, produced in South Gippsland, Australia

Item	Blue water consumption	Water footprint
Total	14.1	1.9
Contribution (% of total):		
Irrigation	0	0
Dairy shed water use	10	2
Animal drinking water	73	12
Purchased feed	2	11
Other farm inputs	15	76

7.2. Canadian example

Dairy Farmers of Canada commissioned a full environmental and socio-economic LCA of Canadian milk production in 2010. The boundaries were from cradle to gate (including transportation to the processor), the functional unit being in line with IDF guidelines (IDF, 2010). This section summarizes the results of the water footprint assessment.

The data inventory used was the same as the primary data used in the full LCA. However, to assess the water footprint of this inventory (supply chain), the Quantis Water Database was used (now available in ecoinvent 3.0). Data were not allocated. For irrigation, national statistics were used. For on-farm water use, recommendations and technical data were used to estimate drinking and cleaning water requirements.

The water footprint of milk production in Canada varies from one region to the next, ranging between 11 and 336 litres of consumed water. However, according to irrigation statistics on feed produced, most farms fall at the lower end of this scale. It is important to note that the irrigated farms represent less than 1% of farms across the country but are concentrated in three provinces, where they represent up to 10.6%. An example of the spread in water use for the irrigated and non-irrigated scenarios is shown in Figure 7. Feed produced on irrigated surfaces contributes greatly to the overall footprint, shifting the weighted Canadian average to 20 litres H_2Oe per kilogramme FPCM. For farms using non-irrigated feed, less than 30% of the water consumption is linked to direct on-farm use (drinking and cleaning water). A greater contribution is linked to water evaporation during energy production for use at various stages of the life cycle. For this reason, it is interesting to note that energy-efficient measures also contribute to reducing the water footprint.

The water stress index (WSI) of Pfister et al. (2009) was used to assess the water stress caused by water consumption. The WSI is used for assessing the competition for water as a function of the ratio of water withdrawal to availability. Because of the low scarcity of water in most sub-watersheds in Canada (Pfister et al., 2009), the overall stress assessment (a product of the WSI and the water footprint) was very low, with a weighted Canadian water availability footprint of 1.1 litres H_2Oe per kilogramme FPCM.

In a further assessment step, the study evaluated the potential endpoint impacts of water withdrawal and consumption on ecosystem quality, human health and resource depletion. The highest contribution came from irrigation water and was highest in British Colombia. However, compared with the overall life cycle impacts of milk production, the contribution of water consumption (2% of total impact on ecosystem quality) was still much lower than other contributors in the same category, coming from different sources such as land use.

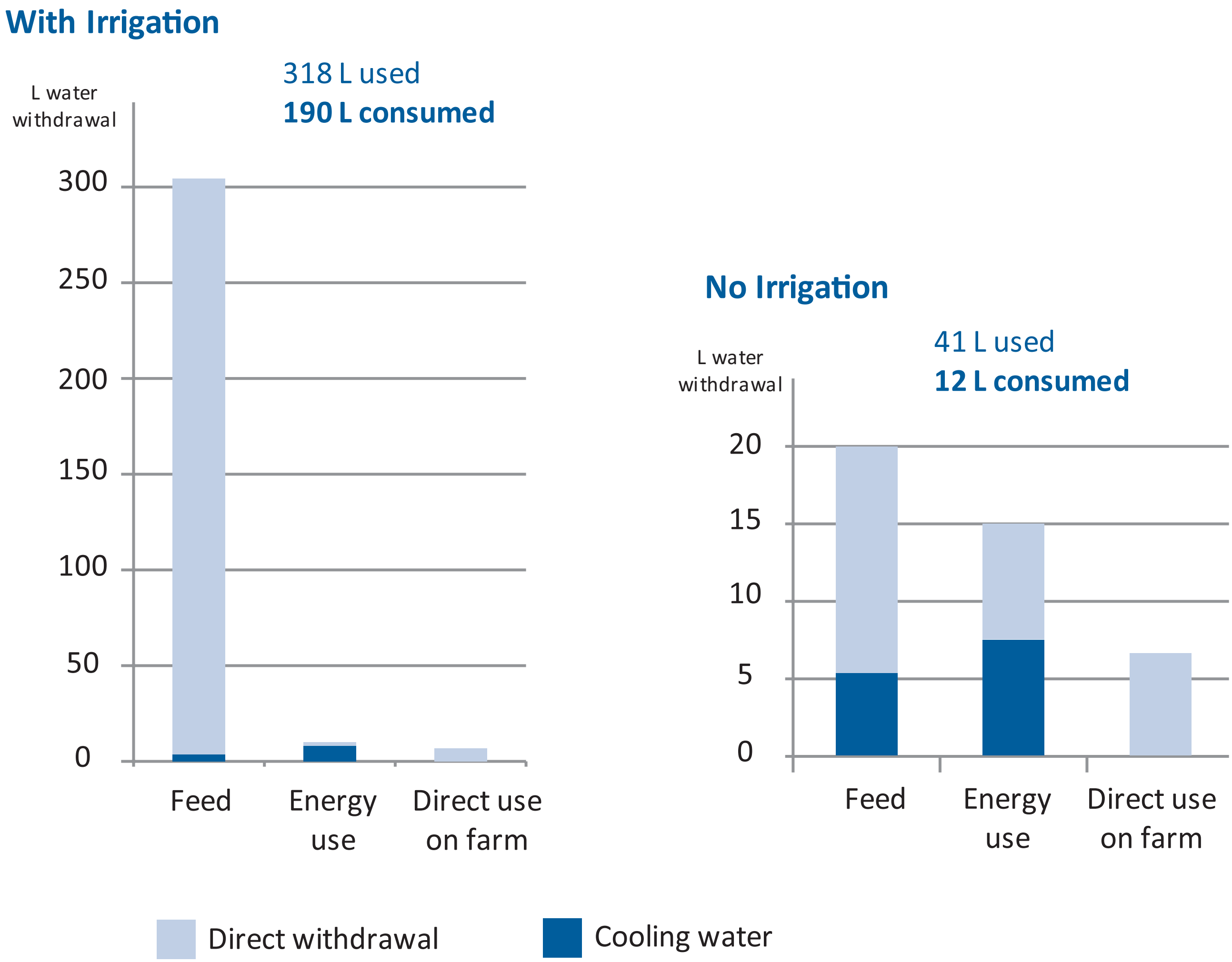

Figure 7: Water withdrawal at different stages, based on two "average" scenarios, with and without irrigation

Overall, some key findings from this aspect of the full LCA for Canada are as follows:

- Little on-farm data exists with regards to water use. It is not a concern for most farmers.
- Water stress is only a concern in the Southern Prairies, coinciding with regions that make use of irrigation.
- Compared with the balance of impacts linked to on-farm activities and the supply chain, water withdrawal and water consumption in regions of low scarcity have a negligible contribution.
- Energy-efficient measures along the supply chain also contribute to reducing the water footprint of milk.

7.3. USA example

The goal of a recent study (Henderson et al., 2013) was to assess overall environmental impacts of milk production in the USA, taking spatial differences into account (e.g. feeding practices and crop production practices). The study built on data collected during a US Dairy greenhouse gas (GHG) study (Thoma et al., 2010), where data were collected at the state, regional and national levels. The five milk-production regions are shown in Figure 8.

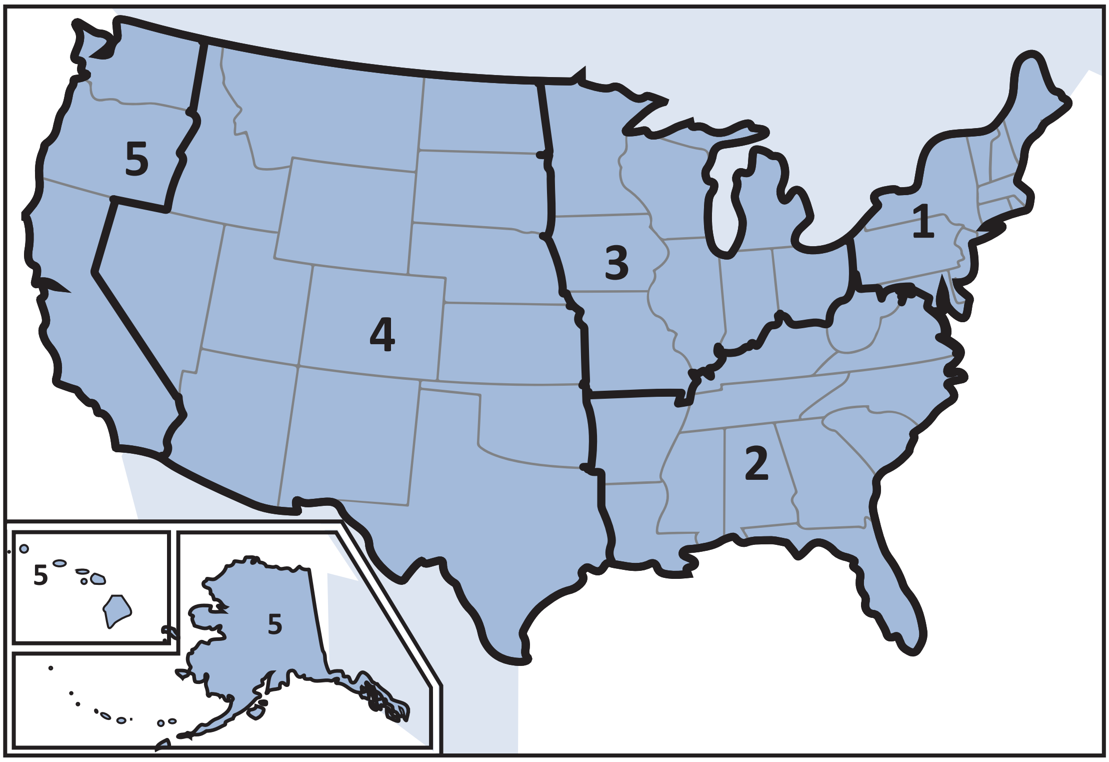

Figure 8: Milk production regions used in the US milk greenhouse gas LCA (Thoma et al., 2010)

The functional unit of the full study was one consumed kilogramme of fat- and protein-corrected milk (FPCM), as defined by the IDF (2010). In this example, however, we focus only on the impacts up to the farm gate (i.e. associated with milk production) and do not consider milk processing, distribution and consumption. Allocation between milk and beef was based on a causal, feed-centred approach that traced energy in feed, resulting in a typical allocation ratio of about 0.89 (milk to beef).

Rations are the crucial connection between milk production and feed. As noted above, feed production is often the dominant contributor to many life cycle impacts. Thoma et al. (2010) surveyed US milk producers and were able to capture 80% of the ration dry matter using 11 feeds; with the remainder modelled as a feed mix of corn and soy. To calculate the water inventory at the dairy level, the regional ration and the state-by-state supply of feed were considered. A matrix approach (Henderson et al., 2013; Asselin et al., 2016) was employed to link consumption of feed in one state to production of that feed in other states, based on a feed transport model. It is crucial to realize that crop production practices vary from location to location, largely due to climatic differences. For example, water requirements for corn grain production vary between states from over 1000 to 0.3 litres per kilogramme of dry matter.

Data collection included state-based yield, irrigation rate and the fraction of produced feed that each state supplies to the others. Also included was the water used on the dairy producing farm for dairy wash water and drinking water for cows.

In this LCA study, only consumed water (i.e. withdrawn from a basin and not returned) was included in the water inventory. Green water, largely natural precipitation, was not considered because using green water for crop production does not constitute a withdrawal nor does it deprive other users.

Life cycle impact assessments at the end-point level allow quantification of impacts related to water consumption on human health and ecosystem quality. However, for the purposes of this demonstration calculation, the focus is only on water stress (Pfister et al., 2009). Connecting the water inventory to impact is crucial: the use of one litre of water in water-stressed and water-rich regions will have different effects.

7.3.1. Water footprint inventory and impact assessment

Figures 9–11 illustrate the variation in water consumed, that is, water inventory (Figure 10) and water stress impact (Figure 11), disaggregated according to feed crop as well as on-farm activity by US watershed (see Figure 9 for watershed numbers)., Variable-width graphs were used to reflect the mix of national production. These show a watershed-level inventory (or impact) on the *y*-axis and the milk production fraction on the *x*-axis. Watersheds are sorted according to descending area, which is the product of both the watershed level inventory or impact and that watershed's milk production importance.

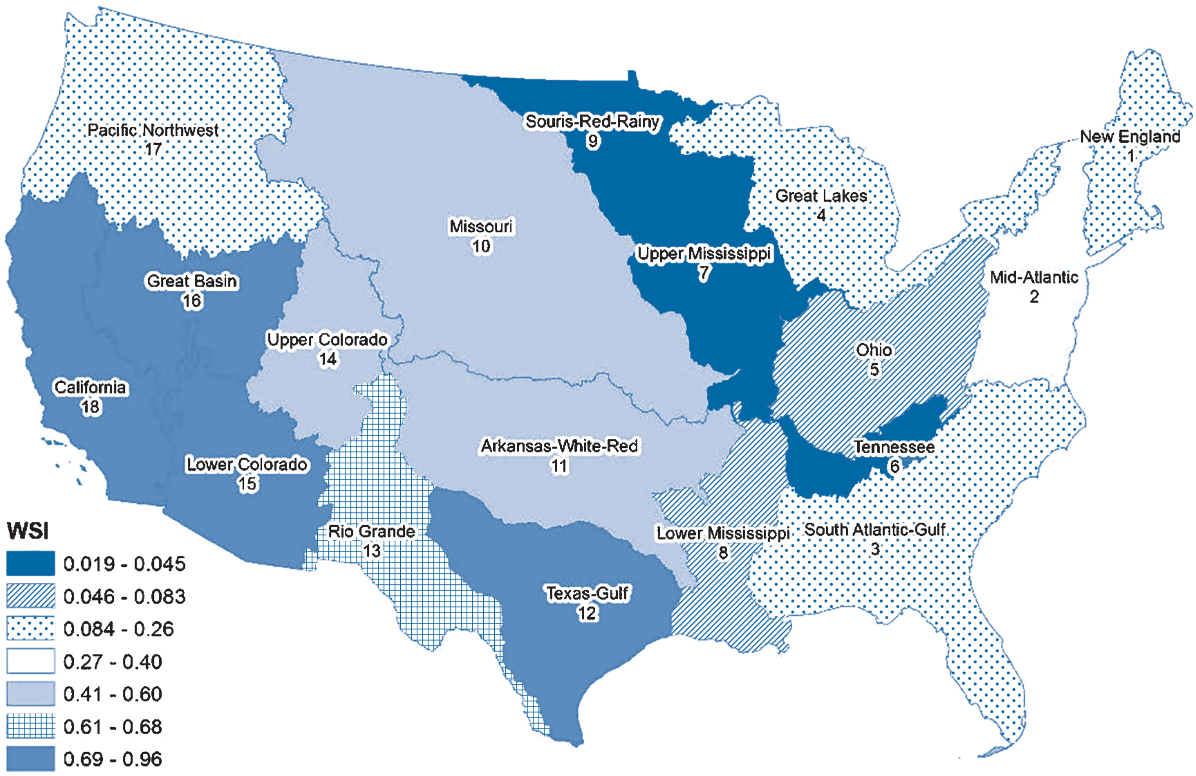

Figure 9: Water stress index (WSI) for US watersheds

Because data are shown disaggregated according to feed, we see in Figure 9 that the main contributors to water inventory are, generally, hays and silages grown locally in watersheds with water scarcity. Water for drinking and parlour washing tend to be relatively small; even areas with abundant water tend to purchase commodity crops that require some irrigation. The watershed-level water consumption ranges from 588 to 12 litres H_2Oe per kilogramme FPCM, and the water stress is 517 to 0.9 litres H_2Oe per kilogramme FPCM.

Depending on climatic conditions, feed supply and rations, just a few watersheds are significant contributors to the national-level milk water inventory. Watersheds may be significant at the national level through high milk production fractions but moderate water inventories, or through moderate production but high water inventory. In the case of the inventory, 95% of the water consumption is due to 50% of milk production; for impact, 98% of water stress is due to 50% of production. The national average water consumption at farm gate is 181 litres H_2Oe per kilogramme FPCM, and the water stress impact is 121 litres H_2Oe per kilogramme FPCM.

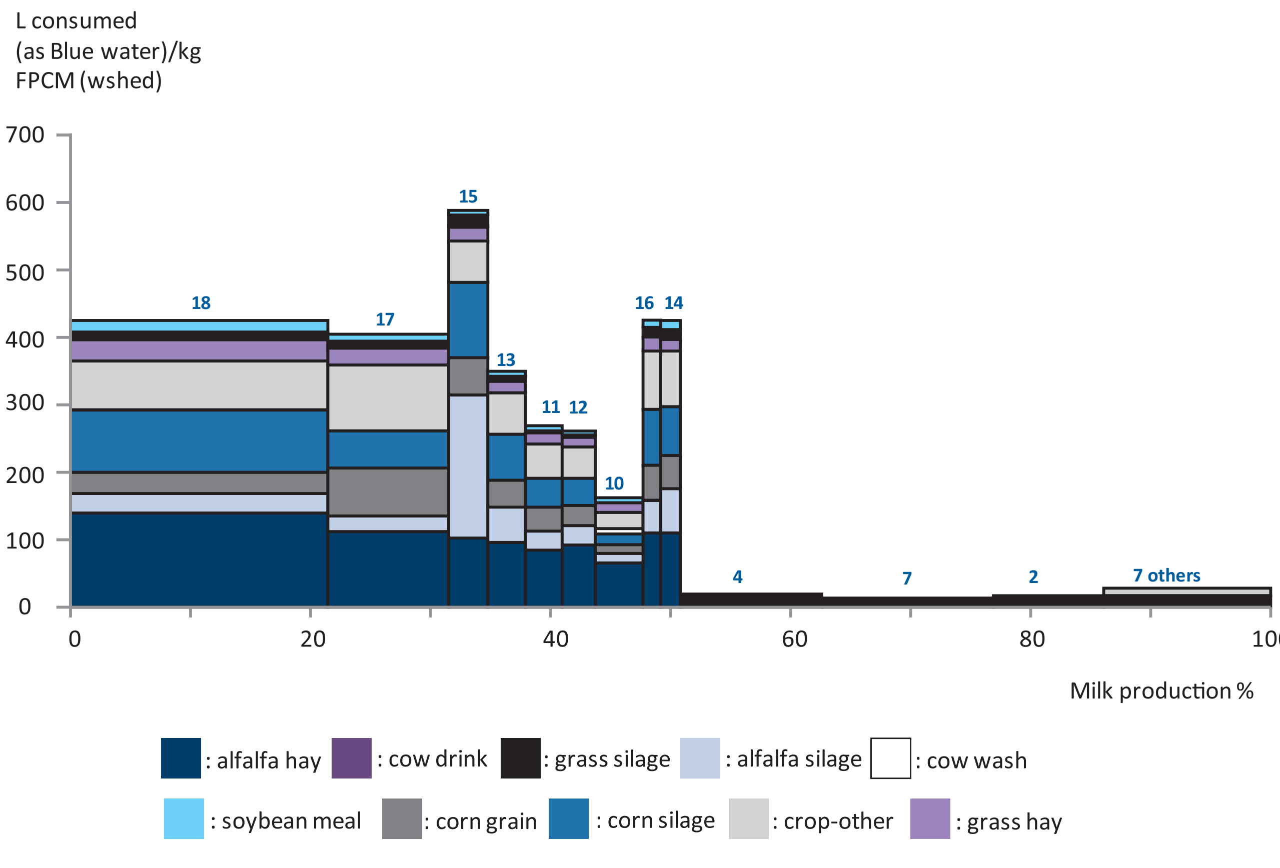

Figure 10: Water use inventory at the national level. Watershed-level inventory is shown on the *y*-axis (litres H_2Oe per kilogramme FPCM) and milk production on the *x*-axis; rectangle area represents overall contribution

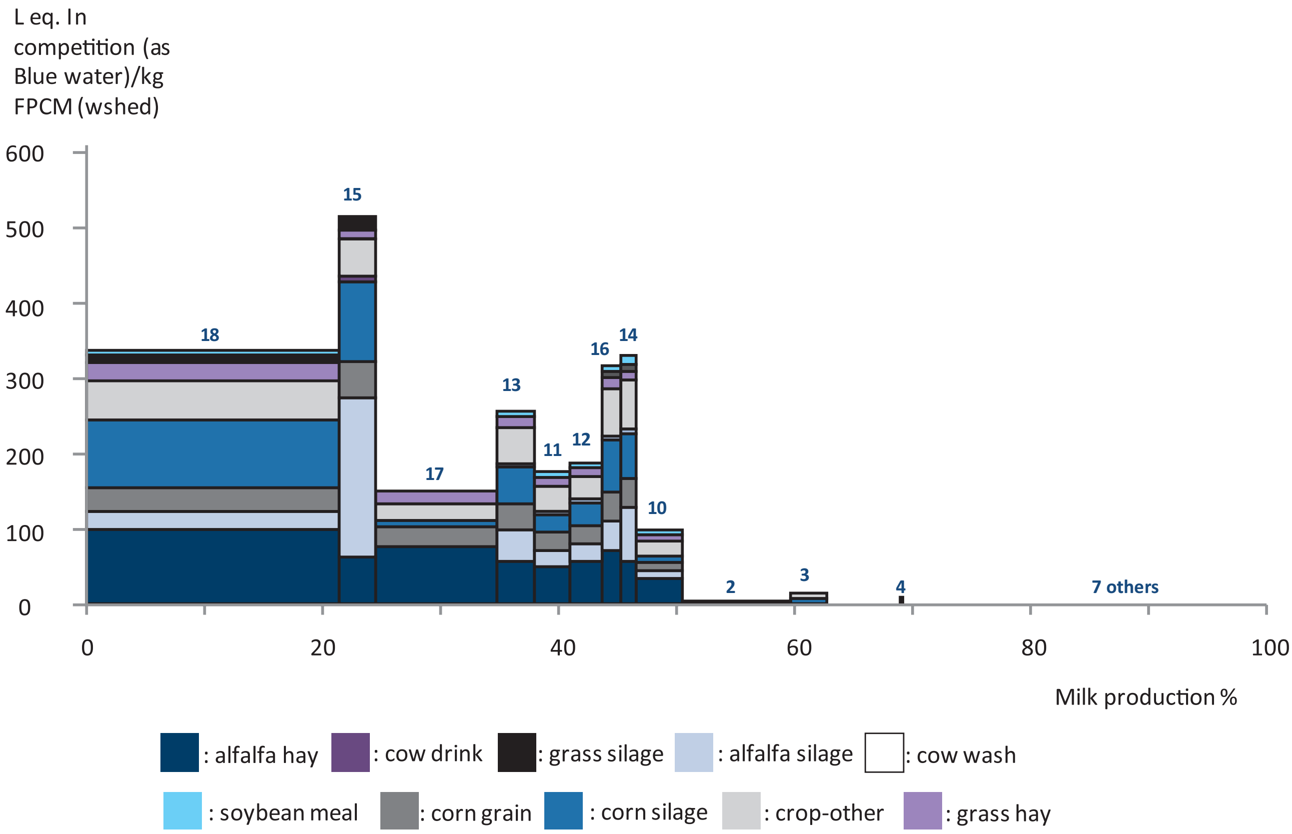

Figure 11: Water use impact at the national level. Watershed-level stress is shown on the *y*-axis (litres H_2Oe per kilogramme FPCM) and milk production on the *x*-axis; rectangle area represents overall contribution to water stress

Overall, this analysis shows the importance of using spatially differentiated values in the water footprint. In contrast to other environmental impacts (e.g. greenhouse gases or land use), the amount of water required to produce feeds varies greatly across geographies. This must be coupled with information about sources of feeds in order to accurately capture the water use – and impact – associated with milk production.

8
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9 DEFINITIONS

The following terms are defined by ISO TC207 SC5 ISO/DIS 14046 *Environmental management – Water footprint – Principles, requirements and guidelines*. When necessary, a dairy-specific definition is provided.

Term	ISO definition	Dairy-specific interpretation if necessary
Terms relating to water		
Water use	Use of water by human activity Note 1: Use includes, but is not limited to, any water withdrawal, water release or other human activity within the drainage basin impacting water flows and quality, including in-stream or in situ uses such as fishing, recreation, transportation	The boundary needs to be clarified. If the focus is the cradle-to-factory-gate stage, water is "used" to produce inputs (such as crops, fertilizers), for drinking, sanitation, parlour processing and dairy factory processing. The US study showed that irrigation water use is: (1) ~90% of water use for cradle-to-grave milk production (2) ~5% of water use occurs on dairy farms where there are three major uses of water: animal drinking, sanitization/cleaning and milk cooling. (3) ~5% of water use is for processing. On the other hand, the Canadian study, in which almost no irrigation is used, showed that most water consumption happens upstream of the farm (mostly in energy production) while less than 30% is due to on-farm water use
Water withdrawal (water abstraction)	Anthropogenic removal of water from any water body or from any drainage basin, either permanently or temporarily	Water removal should include catchment of any type of precipitation water
Water consumption	Water removed but not returned to the same drainage basin due to evaporation, transpiration, product integration or discharge into a different drainage basin or the sea. Evaporation from reservoirs can be included in water consumption. Note: The temporal and geographical coverage of the water footprint assessment should be defined in the goal and scope	Water consumption processes include run-off from irrigation, besides evaporation, transpiration, product integration and discharge into a different drainage basin or the sea (out-flow from the watershed of study to an external one)
Water degradation	Negative change in water quality	

Water quality	Physical (e.g. thermal), chemical and biological characteristics of water with respect to its suitability for an intended use by humans or ecosystem	The intended uses in the dairy sector can be drinking (humans or animals), cleaning (dairy farms and processing plants) or irrigation, all with different quality criteria
Evaporation (Evapotranspira-tion, transpiration)	Mentioned but not defined by ISO	Transfer of water to the atmosphere during the growth of feed, the production of inputs, and during the cooling processes
Water discharge (or water release)	Mentioned but not defined by ISO	Water that enters the geographical limits of the study system, within the time coverage period. It is described as a volumetric water flow (m^3/s, ft^3/s, acre-feet per day)
Recycled water	Not defined by ISO	Water that is degraded and then treated to recover the required quality for an intended subsequent use (inside or outside the boundaries of the study system). Recycled (and reused) water may imply that the inputs and outputs associated with unit processes are to be shared by more than one product system, thus allocation procedures may be required (explained by ISO)
Metabolic water	Not defined by ISO	The water that dairy cattle produce through the metabolic oxidation of organic nutrients
Drinking water intake by cows	Not defined by ISO	The amount of water a cow drinks depends on her size and milk yield, quantity of dry matter consumed, temperature and relative humidity of the environment, temperature of the water, quality and availability of the water and amount of moisture in her feed Note: For lactating cows, drinking or free water intake satisfies 80–90% of the dairy cows' total water needs
Terms relating to types and classifications of water		
Freshwater	Water having a low concentration of dissolved solids. Note 1: Freshwater typically contains less than 1000 milligrams per litre of dissolved solids and is generally accepted as suitable for withdrawal and conventional treatment to produce potable water. Note 2: The concentration of total dissolved solids can vary considerably over space and/or time	

Brackish water	Water containing dissolved solids at a concentration less than that of seawater, but in amounts that exceed normally acceptable standards for municipal, domestic and irrigation uses Note 1: The concentration of total dissolved solids in brackish water can vary from 1000 to 30 000 milligrams per litre. Note 2: The concentration of total dissolved solids of many brackish waters can vary considerably over space and/or time	
Surface water	Water in overland flow and storage, such as rivers and lakes, excluding seawater	
Sea water	Water in a sea or ocean Note: Seawater has a concentration of dissolved solids greater than or equal to 30 000 milligrams per litre.	
Groundwater	Water that is being held in, and can be recovered from, an underground formation	
Blue water	Not defined by ISO	Fresh surface water, groundwater and rainwater stored in artificial ponds
Green water	Not defined by ISO	Water from precipitation that does not run-off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Green water should be measured by taking into account the changes in blue water from use of precipitation (not overall evaporation)
Fossil water	Groundwater body that has a negligible rate of natural recharge on the human time-scale Note: Sometimes, the term “non-renewable water” is used for this concept	
Water body	Accumulation of water that has definite hydrological, hydrogeomorphological, physical, chemical and biological characteristics in a given geographical area Note 1: Examples of water bodies include: lakes, rivers, groundwater, sea, icebergs, glaciers and reservoirs. Note 2: The geographical resolution of a water body should be determined at the goal and scope stage: it may regroup different small water bodies	

Drainage basin	Area from which direct surface runoff from precipitation drains by gravity into a stream or other water body Note 1: Sometimes the terms "watershed", "drainage area", "catchment", "catchment area" or "river basin" are used for the concept of drainage basin. Note 2: Groundwater drainage basin does not necessarily reflect surface drainage basin. Note 3: The geographical resolution of a drainage basin should be determined at the goal and scope stage: it may regroup different sub drainage basins	
Elementary water flow	Water entering the system being studied that has been drawn from the environment, or water leaving the system being studied that is released into the environment	
Wastewater	Not defined by ISO	Water that has been used on the dairy farm or processing plant and contains dissolved or suspended waste materials Note: The production of wastewater is highly influenced by management practices both on-farm and in processing plants. Main on-farm sources include milking centre waste, silage leachate, barnyard runoff and dairy manure. Significant processing plant sources include washing, cleaning and sanitizing of pipelines (metals), pumps, processing equipment, tanks, trucks and filling machines (high N load); start-up, product change over and shut down of HTST and UHT pasteurizers; breaking down of equipment and breaking of packages resulting in spillage during filling operations; and the lubrication of casers, stackers and conveyors.
Irrigation water	Not defined by ISO	Water used to irrigate crops, including those grown to recycle nutrients from manure Note: To maximize nutrient recycling, crop growth should be as vigorous as possible. This sometimes requires irrigation. Thus, flushed wastewater can be disposed of through an irrigation system that often also serves to apply additional amounts of irrigation water to optimize the nutrient recycling

Cleaning water in milking parlour	Not defined by ISO	Water used in post-milking plant cleaning, which is essential for removing bacteria and milk residues from internal plant surfaces, and to control the pathogens that can cause mastitis
Terms relating to life cycle assessment and water footprint assessment		
Water footprint	Metric(s) that quantify(ies) the potential environmental impacts related to water Note: If water-related impacts have not been comprehensively assessed, then the term "water footprint" can only be applied with a qualifier. A qualifier is one or several additional words used in conjunction with the term "water footprint" to describe the impact category/categories studied in the water footprint assessment (e.g. water scarcity footprint, water eutrophication footprint)	
Product water footprint	Not defined by ISO	Includes the evaluation of both water quantity and quality throughout the life cycle of a product within a set of system boundaries, in a specific application and in relation to a defined amount of a specified product Note: The product water footprint consists of: (1) The balance between water withdrawal and water returned to the watershed (also referred to as the consumed water) (2) An evaluation of all environmentally relevant attributes or aspects of the natural environment, human health and resources related to water degradation Environmental impacts related to water consumption can occur in the dairy sector when the withdrawal of water (for irrigation, cow's drinking water) affects the availability of water resources (in surface or groundwater bodies) with consequences on the functioning of ecosystems (loss of species) and/or human health (malnutrition, spread of diseases).

		Environmental impacts from the dairy sector in terms of water degradation may occur when nitrogen and phosphorus from an excess of soil fertilizers leach into the groundwater and into other receiving water bodies (a lake/river or an estuary) in large quantities, increasing eutrophication. This could have an impact on the ecological functioning of the aquatic ecosystem (algal blooms, oxygen depletion, changes in biological communities, decline of certain aquatic species). It could also impact human health if the water body is used as a source of drinking water. Environmental impacts can also arise from chemical pollutants derived from the use of pesticides on dairy farms. These can also reach water bodies by leaching to the groundwater system or by run-off to surface water. Chemical pollution can have severe impacts on the biological populations of aquatic ecosystems and on human health (if sources of drinking water are affected)
Water footprint assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts related to water used or affected by a product, process or organization Note: In ISO 14046 the term “study” is often used as synonym for “water footprint assessment”	
Comprehensive water footprint assessment	Water footprint assessment that fulfils the principle of comprehensiveness Note: The principle of comprehensiveness states that a water footprint considers all environmentally relevant attributes or aspects of the natural environment, human health and resources related to water (including water availability and water degradation)	
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal	
Life cycle assessment (LCA)	Compilation and evaluation of the inputs, outputs and potential environmental impact(s) of a product system throughout its life cycle	

Life cycle inventory analysis (LCIA)	Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle	
Water footprint inventory analysis	Phase of water footprint assessment involving compilation and quantification of inputs and outputs related to water for products, processes or organizations as defined in the goal and scope Note: This includes, where relevant, air, water and soil emissions with impacts on water quality	
System boundary	Set of criteria specifying which unit processes are part of a product system or the activities of an organization	Cradle-to-factory-gate-out Note: “cradle” includes feed production, and “factory-gate-out” includes processing
Cut-off criteria	Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study	
Water footprint impact assessment	Phase of a water footprint assessment following the water footprint inventory analysis, aimed at understanding and evaluating the magnitude and significance of the potential environmental impact(s) related to water of a product, process or organization	
Impact category	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned	
Impact category indicator	Quantifiable representation of an impact category Note: The shorter expression “category indicator” can be used for improved readability	

Water footprint profile	Compilation of impact category indicator results addressing potential environmental impacts related to water Note: If a water footprint profile is comprehensive, it can be named “water footprint profile” without any qualifier – the results of this water footprint profile can be named water footprint. If a water footprint profile is not comprehensive, it needs to be preceded by the qualifier “not-comprehensive”, and its result has to be named with a qualifier “non-comprehensive” (being “non-comprehensive water footprint”)	
Characterization factor	Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator Note: The common unit allows calculation of the category indicator result	
Environmental mechanism	System of physical, chemical and biological processes for a given impact category, linking the life cycle inventory analysis results to category indicators and to category endpoints	
Water availability	Extent to which humans and ecosystems have sufficient water resources for their needs Note 1: Water availability depends on the location and timing. The temporal and geographical coverage and resolution for evaluating water availability depends on the goal and scope Note 2: Water quality can also influence availability (e.g. if quality is not sufficient to meet users’ needs) Note 3: Land management (e.g. forestry, agriculture, conservation of wetlands, hydropower) can modify water availability (e.g. regulating river flows and recharging groundwater) Note 4: If water availability only considers water quantity, it is called water scarcity	

Water scarcity	Extent to which demand for water compares to the replenishment of water in an area (e.g. a drainage basin), without taking into account the water quality	Water scarcity (freshwater scarcity) relates natural water availability and natural water needs. A situation is water scarce independently of the current water use or consumption. Water-scarce areas are vulnerable to water stress but can also be "unstressed" (water scarcity is one main factor of water stress)
Water stress	Not defined by ISO	Water stress represents the current level of stress as a function of use and availability, and can be caused by degradative as well as consumptive use. The stress is induced by human activities and this can occur in water-scarce and water-abundant regions. It does not account for mitigation capability/ vulnerability of the population, as this is how the stress impacts the ecosystem and/or humans (this is LCA endpoint impact assessment). Stress is caused by a stressor, which is human water use (pollution and consumption)
Partial water footprint	Not defined by ISO	A water footprint that does not consider all environmentally relevant attributes or aspects of the natural environment, human health and resources related to water (including water availability and water degradation)
Terms relating to interpretation and reporting of water footprint results		
Organization	Person or group of people that has its own functions with responsibilities, authorities and relationships to achieve its objectives	Includes feed (and other input) suppliers, dairy farm, dairy processor, dairy cooperative, retailers, consumers and policy makers
Comparative assertion	Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function	
Interested party	Individual or group concerned with or affected by the environmental performance of a product system, process or organization, or by the results of the water footprint assessment or the life cycle assessment	

Terms relating to products, product systems, processes and organizations		
Product	Goods or service Note: The product can be categorized as follows: - Service (e.g. transport, implementation of events) - Software (e.g. computer program, dictionary) - Hardware (e.g. engine mechanical part) - Processed material (e.g. steel) - Agricultural and forest products (e.g. food, lumber, paper)	In the dairy sector it refers to any dairy product or to raw milk
Co-product	Any of two or more products coming from the same unit process or product system	
Waste	Substances or objects which the holder intends or is required to dispose of	
Product system	Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product	
Process	Set of interrelated or interacting activities that transforms inputs into outputs	
Unit process	Smallest element considered in the life cycle inventory analysis for which input and output data are quantified	
Functional unit	Quantified performance of a product system, process or organization for use as a reference unit	Needs to be set (e.g. litres of H_2O equivalents per kilogramme product) Product needs to be defined: cradle-to-farm gate in kilogrammes of fat- and protein-corrected milk (FPCM) cradle–to-factory gate in kilogrammes of fluid milk product cradle-to-factory gate in kilogrammes of whole milk powder (WMP)

Fat- and protein-corrected milk (FPCM)	Not defined by ISO	The functional unit for studies conducted on-farm. It represents one kilogramme of fat- and protein-corrected milk at the farm gate in the country in which the analysis is taking place. Note 1: Using FPCM as the basis for farm comparisons assures a fair comparison between farms with different breeds or feed regimes. FPCM is calculated by multiplying milk production by the ratio of the energy content of a specific farm's (or region's) milk, to the energy content of standard milk with 4% fat and 3.3% true protein content. The formula for calculating the functional unit for farming is: FPCM (kg/year) = Production (kg/year) × [0.1226×Fat% + 0.0776×True Protein% + 0.2534]
Reference flow	Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit	
Product category	Group of products that can fulfil equivalent functions	
Product category rules	Set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories Note: Product category rules are compliant with ISO 14044	
Reporting unit	Quantified performance of the studied organization for use as a reference unit for the calculations Note: In the case of application of a water footprint to an organization, the functional unit is replaced by the reporting unit	
Facility	Single installations, set of installations or production processes (stationary or mobile), which can be defined within a single geographical boundary, organizational unit or production process	
Water footprint inventory	Result of a water footprint inventory analysis, including elementary flows which are usable for subsequent water footprint impact assessment	

Direct water footprint inventory	Water footprint inventory considering inputs and outputs resulting from activities within the established organizational boundaries, reflecting the type of water footprint assessment	
Indirect water footprint inventory	Water footprint inventory considering inputs and outputs which are consequences of an organization's activities but arises from processes that are owned or controlled by other organizations, reflecting the type of water footprint assessment	
Terms relating to data and data quality		
Primary data (specific data, site-specific data)	Quantified value within a unit process or an activity within the product system originating from a direct measurement, activity data or a calculation based on direct measurements at its original source	
Secondary data (generic data)	Quantified value within a unit process or an activity within a product system obtained from sources other than direct measurement or calculation from direct measurements, such as databases and published literature	
Uncertainty analysis	Systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty or data variability Note: Either ranges or probability distributions are used to determine uncertainty in the results	
Transparency	Sufficient and appropriate information is disclosed in order to allow users of the water footprint assessment to make decisions with reasonable confidence	

APPENDICES

I. Data needed to calculate water footprint at the dairy farm level for consumptive water use*

On farm

- Quantity of electricity
- Quantity of diesel
- Quantity of petrol use
- Quantity of water withdrawal (often need to be estimated)
- Type of water and its source (for drinking and cleaning)
- Percentage manure/slurry
- Days of full grazing
- Quantity of cleaning water
- Type of irrigation system
- Rainfall
- Temperature

Crops and pasture (on and off farm)

- Quantity of irrigation water
- Quantity of N, P, K fertilizer used for each crop and pasture
- Type of mineral fertilizer
- Amount of seeds

Animals

- For each type of animal:
    - Number of animals
    - Type of feed and quantity
    - Composition of concentrate
- Type, quantity and live weight of sold animals
- Quantity of milk sold, including fat% and protein%
- Type of milking parlour

* suggested list, not exhaustive

II. Scales of impact assessment

Farm scale

Data to be collected at this scale are described in Section 5.1. Assessments of the impacts on water quality at the farm scale are typically restricted to quantification of pressures (local accumulation of potential pollutants that could be transported to water bodies; see Section 6.0). In most cases, the quantification of pressures is relatively straightforward and LCA models can be used to translate the water consumption and pressures on water degradation into potential impacts on ecosystems and human health.

Catchment scale

This is the scale at which agriculture impacts on water quality and water scarcity. It is also the scale at which most national monitoring programmes (see the Canadian and the USA examples in Section 7) and water quality models operate (EPA, 2016). However, there are significant challenges associated with quantification at the catchment scale. Water quality and scarcity at catchment scale is an aggregate of impacts from a variety of farms and land uses – it is typically difficult to disentangle impacts from individual farms or farming systems. Moreover, water quality is also an aggregate of current and past land use management practices, due to in-stream sorption and desorption processes. As a result, water quality at the catchment scale typically responds only very slowly (years to decades) to changes in land management (e.g. Kronvang, 2009; Schulte et al., 2010; Fenton et al., 2011; O'Dwyer et al., 2013).

Intermediate scale

In water quality assessment, we can define an intermediate scale that is a more immediate and direct representation of land use management and/or farming practices. This is the appropriate scale to include the transport and transformation of a potential pollutant (pressure) to the final impact in the receiving water bodies (receptors); these are known as pathway processes (see Section 6.0).

The challenge of measurement and modelling at intermediate scales is the variability of the parameters over space and time[17]. As a result of spatial variation in soil characteristics, in many landscapes it is not possible to predict pathways with any level of accuracy without extensive empirical measurements. The difficulty of assessing intermediate mechanisms is further exacerbated when landscape factors are considered[18].

17 For example, it is possible that two farms within the same landscape, both with the same nitrogen surplus of 100 kg/ha/year impact differently on the aquatic environment as a result of local differences in soil type: one farm could have full denitrification and very low groundwater nitrate concentrations, whereas another farm could have no denitrification, resulting in nitrate levels in excess of WHO standards.

18 For example, one farm could be set within a very intensive farming landscape with a lot of point sources where there is no dilution of any nutrients, whereas another farm could be a single entity within a much wider catchment with very little pressures, allowing nitrates lost to be diluted very quickly so that the concentrations are not problematic.

III. Sources of losses affecting water quality at the farm level

Environmental impacts from degradative water use often occur when agricultural inputs such as nutrients and/or pesticides are (partially) lost from the farming system and enter into water bodies such as rivers, lakes, groundwater or estuaries. In general, three types of losses are recognized (Jennings et al., 2003):

- **Point source losses**: concentrated losses of inputs (e.g. nutrients) from defined spaces (e.g. farm yards, storage tanks) to water bodies. Non-agricultural point sources of nutrient loss can include septic tanks and wastewater treatment facilities. Point source losses can typically be prevented by technological/infrastructural measures.

- **Diffuse source losses**: loss of inputs (e.g. nutrients) in low concentrations from large areas. Examples include nutrient losses from fields with high concentrations of soil nutrients, reflecting historic and current nutrient management practices. Diffuse losses may typically be sustained over long time periods, even after changes in nutrient management practices (see e.g. Fenton et al., 2011 for nitrogen and Schulte et al., 2010 for phosphorus).

- **Incidental losses**: direct losses from inputs to water through misplacement of, for example, fertilizer or pesticides, either temporally or spatially. An example of spatially incidental loss is the accidental entry of fertilizer into water bodies through inaccurate distancing of the spreader to the watercourse. An example of temporally incidental loss is the land spreading of animal manure at times of overland flow. In either case, incidental losses are characterized by their short duration, resulting in loss “spikes”.

IV. Ameliorating factors through pathways

Not all of the nutrients or other farm inputs that are initially lost by water transport end up in the receiving water body. Typically, ameliorating factors reduce the concentration of nutrients/inputs along the pathway, through **attenuation** or **biochemical processes** (Schulte et al., 2014).

For nitrogen, denitrification of nitrates is the most important process. As a result, nitrate concentrations in deep groundwater and surface water tend to be much lower than nitrate concentrations in water immediately below the rooting zone (Mellander et al., 2012). The end product of the denitrification process depends on the aerobic conditions of the soil, ranging from nitrous oxides (a powerful greenhouse gas) on moderately drained soils to di-nitrogen (an inert benign gas) on poorly drained soils. On well-drained, aerobic soils, denitrification rates are low.

For phosphorus and other farm inputs (e.g. pesticides, metals from sewage sludge), attenuation is the most important ameliorating factor. Attenuation can result from physical processes through adsorption to the soil matrix, depending on the sorption capacity of the soil, which in turn is a function of the physical and chemical parameters of the soil (e.g. Daly et al., 2001). Alternatively, attenuation can be mediated by biological processes through uptake into the biomass, both below ground (soil biome) (e.g. Bourke et al., 2008; Massey et al., 2013) and above ground (e.g. wetlands, riparian zones) (e.g. Dunne et al., 2005; Schulte et al., 2009).

THE IDF GUIDE TO WATER FOOTPRINT METHODOLOGY FOR THE DAIRY SECTOR

ABSTRACT

These guidelines are intended to reach better understanding of water footprint assessment within the dairy sector. They provide transparency about a dairy product's water profile throughout its life cycle to allow monitoring, quantification and evaluation of the potential environmental impacts related to water use. The document reviews previous work on life cycle assessment and provides guidelines on standardization of water footprint. The guidelines followed ISO 14046, and are aligned with the LEAP guidelines for water use that cover all livestock sectors.

Keywords: *water footprint assessment, life cycle assessment, environmental impact, dairy products, dairy farm*

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Example: 1 Singh, H. & Creamer, L.K. Aggregation & dissociation of milk protein complexes in heated reconstituted skim milks. J. Food Sci. 56:238-246 (1991).

Example: 2 Walstra, P. The role of proteins in the stabilization of emulsions. In: G.O. Phillips, D.J. Wedlock & P.A. William (Editors), Gums & Stabilizers in the Food Industry - 4. IRL Press, Oxford (1988).

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ANNEX 1

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"	Usually double quotes and not single quotes
? !	Half-space before and after question marks, and exclamation marks
±	Half-space before and after
micr<u>oo</u>rganisms	Without a hyphen
Infra-red	With a hyphen
et al.	Not underlined nor italic
e.g., i.e.,...	Spelled out in English - for example, that is
lit<u>re</u>	Not liter unless the author is American
ml, mg,...	Space between number and ml, mg,...
skimmilk	One word if adjective, two words if substantive
sulfuric, sulfite, sulfate	Not sulphuric, sulphite, sulphate (as agreed by IUPAC)
AOAC <u>INTERNATIONAL</u>	Not AOAC<u>I</u>
progra<u>mme</u>	Not program unless a) author is American or b) computer program
milk and milk product	rather than "milk and dairy product" - Normally some latitude can be allowed in non scientific texts
-ize, -ization	Not -ise, -isation with a few exceptions
Decimal comma	in Standards (only) in both languages (as agreed by ISO)

No space between figure and % - i.e. 6%, etc.

Milkfat	One word
USA, UK, GB	No stops
Figure	To be written out in full
1000-9000	No comma
10 000, etc.	No comma, but space
hours	Ø h
second	Ø s
litre	Ø l

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