Food and Agriculture Organization of the United Nations

DRAFT FOR PUBLIC REVIEW

Water use of livestock production systems and supply chains

Guidelines for assessment

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Recommended citation
FAO. 2018. *Water use of livestock production systems and supply chains – Guidelines for assessment (Draft for public review).* Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

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Foreword

The Technical Advisory Group, (TAG) on water use assessment, hereafter called Water TAG, is composed of experts from various backgrounds and areas of research and extension services, including water footprinting, water footprints of livestock supply chains, animal science, soil science, agriculture science, hydrology, capacity development, and Life Cycle Assessment (LCA). The Water TAG was formed by the Livestock Environmental Assessment and Performance (LEAP) Partnership.

LEAP guidelines on water use assessment can be used in conjunction with other LEAP guidelines on feed small ruminants, poultry, large ruminants and pig supply chains depending on goal and scope of the assessment.

Acknowledgements

These guidelines are a product of the Livestock Environmental Assessment and Performance (LEAP) Partnership. The following groups contributed to their development:

The Technical Advisory Group (TAG) on Water Footprinting conducted the background research and developed the core technical content of the guidelines. The TAG on Water Footprinting was composed of: Anne-Marie Boulay (co-chair, Sherbrooke University (LIRIDE) and Polytechnique Montreal (CIRAIG), Canada); Katrin Drastig (Co-chair, Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB), Germany), Stephan Pfister (Technical supervisor, ETH Zurich, Swiss); Members included: Alessandro Manzardo (Centro Studi Qualità Ambiente-Università degli Studi di Padova, Italy), Amanullah (The University of Agriculture Peshawar, Pakistan), Arjen Hokstra (University of Twente, Netherlands); Armelle Gac (French Livestock Institute, France); Ashok Chapagain (University of the Free State, South Africa); Aung Moe (Alberta Agriculture and Forestry, Canada); Barbara Civit (CONICET-UTN FRM, Argentina); Brad Ridoutt (CSIRO, Australia); Davy Vanham (JRC, Italy); Ernesto Reyes (Agribenchmark, Colombia) Giacomo Pirlo (Centro di ricerca per le Produzioni Foraggere e Lattiero-Casearie, Italy) Gloria Salmoral (University of Exeter, UK); Julio Cesar Pascale Palhares (Embrapa Southeast Livestock, Brazil); Liu Junguo (South University of Science and Technology of China, China); Maite Aldaya (UNEP-Public University of Navarra, Spain); Marlos DeSouza (FAO Water and Land use Department, Italy); Masaharu Motoshita (National Institute of Advanced Industrial Science and Technology, Japan); Michael Lathuillière (University of British Columbia, Canada) Ranvir Singh (Soil and Earth Sciences Group, Massey University, New Zealand); Ricardo Morales (AgroDer, Mexico); Ridha Ibidhi (National Institute of Agricultural Research of Tunisia, Tunisia); Sophie Bertrand (IDF-CNIEL, France); Steve Wiedemann (University of New England, Australia); Tim Hess (Cranfield University, UK);Tim McAllister (Agriculture and Agri-Food Canada , Canada); Valentina Russo (University of Cape Town, South Africa); Veronica Charlon (INTA EEA Rafaela, Argentina); Weichao Zheng (China Agricultural University, China). Observers: Nicolas Martin (FEFAC, France); Getahun Gizaw (Manitoba Institute of Agrologists (MIA), Canada); Helena Ponstein (Leibniz Institute for Agricultural Engineering and Bioeconomy, Germany).

The LEAP Secretariat coordinated and facilitated the work of the TAG, guided and contributed to the content development and ensured coherence between the various guidelines. The LEAP secretariat, hosted at FAO, was composed of: Carolyn Opio (Coordinator), Camillo De Camillis (LEAP manager), Félix Teillard (Technical officer) and Aimable Uwizeye (Technical Officer).

- Steering committee members: Alejandro Acosta (Food and Agriculture Organization of the United Nations, Global Agenda For Sustainable Livestock); Monikka Agarwal (World Alliance of Mobile Indigenous People); Douglas Brown (World Vision); Giuseppe Luca Capodieci (The European Livestock And Meat Trading Union, International Meat Secretariat); Camillo De Camillis (Food and Agriculture Organization of the United Nation); Richard de Mooij (The European Livestock And Meat Trading Union, International Meat Secretariat); Elsa Delcombel (Government of France); Lalji Desai (World Alliance of Mobile Indigenous People); Jeroen Dijkman (Food and Agriculture Organization of the United Nations, Global Agenda For Sustainable Livestock); Neil Fraser (Food and Agriculture Organization of the United Nations, Global Agenda For Sustainable Livestock); Pierre Gerber (Food and Agriculture Organization of the United Nations); Mathias Ginet (Government of France); Jan Grenz (Bern University of Applied Sciences, Government of Switzerland); Vincent Guyonnet (International Egg Commission); Dave Harrison (International Meat Secretariat); Matthew Hooper (Government of New Zealand); Hsin Huang (International Meat Secretariat); Delanie Kellon (International Dairy Federation); Lionel Launois (Government of France); Pablo Manzano (International Union for Conservation of Nature); Nicolas Martin (European Feed Manufacturers' Federation, The International Feed Industry Federation); Ian McConnel (World Wide Fund for Nature); Paul Melville (Government of New Zealand); Paul McKiernan (Government of Ireland); Frank Mitloehner (University of California, Davis, The International Feed Industry Federation); Anne-Marie Neeteson-van Nieuwenhoven (International Poultry Council); Frank O'Mara (Teagasc, Government of Ireland); Antonio Onorati (International Planning Committee for World Food Sovereignty); Carolyn Opio (Food and Agriculture Organization of the United Nations); Lara Sanfrancesco (International Poultry Council); Fritz Schneider (Bern University of Applied Sciences, Government of Switzerland); Rogier Schulte (Teagasc, Government of Ireland); Henning Steinfeld (Food and Agriculture Organization of the United Nations); Nico van Belzen (International Dairy Federation); Elsbeth Visser (Government of the Netherlands); Alison Watson (Food and Agriculture Organization of the United Nations); Bryan Weech (World Wide Fund for Nature); Geert Westenbrink (Government of the Netherlands); Hans-Peter Zerfas (World Vision).
- Observers: Rudolph De Jong (International Wool Textile Organization); Matthias Finkbeiner (International Organization for Standardization); Michele Galatola (European Commission, DG Environment); James Lomax (United Nations Environment Programme); Llorenç Milà i Canals (United Nations Environment Programme); Paul Pearson (International Council of Tanners), in LEAP since Feb 2015; Erwan Saouter (European Commission, DG Joint Research Centre); Sonia Valdivia (United Nations Environment Programme); Elisabeth van Delden (International Wool Textile Organization).

LEAP is funded by its Members, with additional support from FAO and the Mitigation of Climate Change in Agriculture (MICCA) Programme.

Although not directly responsible for the preparation of these guidelines, the other TAGs of the LEAP Partnership indirectly contributed to the preparation of this technical document.

Multi-step review process

The initial draft guidelines developed by the TAG over 2016 to 2018 went through an external peer review before its submission for public review.
Jennie Barron (Swedish University of Agricultural Sciences (SLU), Sweden), Mats Lannerstad (ILRI former employee, independent consultant, Sweden), Francisco Salazar Sperberg (INIA, Chile), Jing Huang (Southwest University of Science and Technology, China), Nydia Suppen-Reynaga (Center for LCA and Sustainable Design, ISO 14046 vice-chair) peer reviewed these guidelines in the end of 2017.
The LEAP Secretariat reviewed this technical guidance before its submission for both external peer review and public review. The LEAP Steering Committee also reviewed the guidelines at various stages of their development and provided additional feedback before clearing their release for public review.

Glossary

Terms relating to feed and food supply chains

Abattoir	An animal slaughterhouse.
Arable land	Land on which the vegetation is dominated by production of field crops (e.g. maize, wheat, and soybean production etc.).
Cultivation	Activities related to the propagation, growing and harvesting of plants including activities to create favorable conditions for their growth.
Feed	Any single or multiple materials, whether processed, semi-processed or raw, which is intended to be fed directly to food producing animals (FAO/WHO, Codex Alimentarius CAC/RC 54-2004, amended in 2008).
Fodder	Forage harvested, from both cultivated and non-cultivated land, fed intact to livestock, which can include fresh and dried forage.
Silage	Forage harvested and preserved (at high moisture contents generally >500 g kg^{-1}) by organic acids produced during partial anaerobic fermentation.

Terms relating to different livestock supply chains

Backyard system	Production that is mainly subsistence-driven or for local markets, displaying animal performance lower than in commercial systems and mostly relying on swill and locally-sourced materials to feed animals (less than 20 percent of purchased concentrate). Backyard production systems are the most basic traditional system of keeping animals and the most common in developing countries, in both urban and rural areas. These systems are typically semi-intensive production; they are the most basic traditional system of keeping pigs and the most common in Asian and African countries.
Beef	Beef is the culinary name for meat from bovines, especially domestic cattle, although beef also refers to the meat from the other bovines: antelope, African buffalo, bison, water buffalo and yak.
Broiler	Chicken reared for meat.
Buffalo	Popularly known as water buffalo or domestic Asian water buffalo (*Bubalus bubalis*) is a large Bovidae that originated from India and found on the Indian subcontinent to Vietnam and Peninsular Malaysia, in Sri Lanka, in the Philippines, and in Borneo, used as draught animals and also suitable for milk production. Also known as carabao. In addition, buffalo are also found in in North America and are known as American bison (Bison bison). Bisons also occur in Poland. European bison (*Bison bonasus*), are also known as wisent. In Europe buffalos are widely used for milk production to produce mozzarella cheese.
Calf	Bovine offspring of either sex below the age of one year.
Carcass Weight (CW) or Dressed Weight of the animal	Refers to the weight after slaughter and removal of most internal organs, head (cattle and poultry), and skin (ruminants).
Cow	The mature female of a bovine animal.

Dairy farm	A dairy farm is an agricultural facility to raise and maintain animals for the harvesting or processing (or both) of animal milk – mostly from cows or goats, but also from buffaloes, sheep, horses, or camels – for human consumption.
Extensive farming system	Extensive farming system is a low input, low output and resulting low intensity system, it uses small inputs of labor, fertilizers, and capital, relative to the land area being farmed. In less developed regions, it is often small-scale and mixed cropping subsistence farming systems. In more/highly developed regions examples include cattle and sheep grazing systems.
Flock	A group of poultry
FPCM	Fat and protein corrected milk [kg].
Grasslands	A large open area of country covered with grass, especially one used for grazing.
Graze	Animals feeding directly on growing grass, pasture or forage crops.
Hay	Harvested forage preserved by drying generally to a moisture content of less than 200 g/kg.
Herd	A group of bovines.
Heifer	A young cow, normally over one year old, that has not produced a calf.
Hide	The skin of a large animal, such as cow or buffalo, which can be used for making leather
Intensive farming system	Intensive farming system is a high input – high output system and resulting high intensity system. It uses high inputs of labor, fertilizers, and capital. It is geographically-concentrated, commercially-oriented, and it associated with a specialized production.
Meat	Fresh, chilled or frozen edible carcass including offal derived from food animals.
Mixed crop-livestock system	A combination of crop and livestock activities in a production system.
Replacement rate	The percentage of adult animals in the herd replaced by younger adult animals each year.
Ruminant	An even-toed or hoofed mammal of the suborder Ruminantia.

Terms relating to life cycle environmental inventory and assessment

Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (ISO 14044:2006, 3.17).
Animal perspiration	The processing or sweating that assists in regulation body temperature through evaporative cooling.
Background process	The background system consists of processes on which no or, at best, indirect influence may be exercised by the decision-maker for which an LCA is carried out. Such processes are called "background processes." (UNEP/SETAC Life

	Cycle Initiative, 2011). In this document, this is referred to as "Indirect", see Indirect Water.
Biomass	Biomass is biogenic material derived from living or recently living organisms. It originates from processes of primary production that convert inorganic chemical compounds, mainly carbon dioxide (CO_2) and water (H_2O), into sugars and other energy-rich organic compounds that build up the bodies of plants, animals, and micro-organisms.
Blue water	Freshwater flows originating from runoff or percolation, contributing to freshwater lakes, dams, rivers and aquifers. Soil moisture is considered blue water if it originates from blue water added through irrigation or owing to hydrological events, like flooding, from springs or capillary rise.
By-product	Material produced during the processing of livestock or a crop product that is not the primary objective of the production activity (e.g. oil cakes, brans, offal or skins).
Capital goods	Capital goods are final products that have an extended life and are used by the company to manufacture a product; provide a service; or sell, store, and deliver merchandise. In financial accounting, capital goods are treated as fixed assets or as plant, property, and equipment (PP&E). Examples of capital goods include equipment, machinery, buildings, facilities, and vehicles (GHG Protocol, Technical Guidance for Calculating Scope 3 Emissions, Chapter 2, 2013).
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 (ISO 14044:2006, 3.37). The characterization factor represents the degree of impact (on the relevant category indicator) per unit of inventory, e.g. the increase in local water scarcity per m^3 of water consumed. Therefore, the values in the life cycle inventory are multiplied by the relevant characterization factor to estimate potential impacts.
Comparative assertion	Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function. (ISO 14044:2006, 3.6).
Co-product	Product from a plant cultivation system that can either be used directly as feed or as raw material in food or feed processing. In contrast to by-products co-products are any of two or more products coming from the same unit process or product system which are of primary objective and with higher financial value. Any of two or more products coming from the same unit process or product system (ISO 14044:2006, 3.10).
Cradle-to-gate	System boundary including all life-cycle stages from raw material extraction (cradle) to the gate of the production phase.
Critical review	Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment (ISO 14044:2006, 3.45).
Crop coefficient	Plant parameter used in predicting evapotranspiration. The crop coefficient, Kc, is the ratio of Evapotranspiration observed for the crop (ET_c) over the reference Evapotranspiration (ET_0) of a grass reference crop under the same conditions. In the dual crop coefficient approach, the crop coefficient is split into two factors describing separately the differences in evaporation and transpiration between the crop and reference surface.
Data quality	Characteristics of data that relate to their ability to satisfy stated requirements (ISO 14044:2006, 3.19).

Direct water	Direct water consumption (foreground) refers to water consumption that is within the control of the focus of the study. For example, if the study is at farm-level, on-farm water consumption would be direct. If the study was of a business (e.g. a dairy) then water consumption within the factory would be direct water consumption. Conversely, indirect water consumption (background) is outside of the control of the focus of the study (e.g. water consumption in the supply chain of inputs).
Downstream	LCA terminology: Occurring along a product supply chain after the point of referral. (Product Environmental Footprint Guide, European Commission, 2013). Hydrologic terminology: Direction in which a fluid is moving.
Drainage basin	Area from which direct surface runoff from precipitation drains by gravity into a stream or other water body (ISO 14046:2014, 3.1.8).
Economic value	Average market value of a product at the point of production possibly over a 5-year time frame (Adapted from PAS 2050:2011, 3.17). Note 1: Whereas barter is in place, the economic value of the commodity traded can be calculated on the basis of the market value and amount of the commodity exchanged.
Effective rainfall	The effective rainfall/precipitation (P_e) is the fraction of the total amount of rainwater that is retained in the root zone and can be used by plants, and defined as total rainfall subtracted by evaporation, runoff and deep percolation.
Elementary flow	Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation (ISO 14044:2006, 3.12). Example: flow of water pumped directly from the river/lake for irrigation.
Emissions	Release of a substance to air, water or soil.
Environmental impact	Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services (ISO 14001:2015). Example: contribution to water scarcity.
Evaporation	The change of phase of water from liquid to vapour from any surface at a temperature below boiling point.
Evapotranspiration	Quantity of water transferred from the soil to the atmosphere by evaporation and plant transpiration.
Foreground system	**See Direct water**
Functional Unit	Quantified performance of a product system for use as a reference unit (ISO 14044:2006. 3.20)
Green water	Precipitation that is stored as soil moisture and eventually transpired or evaporated
Indirect water	Indirect water consumption (background) is outside of the control of the focus of the study (e.g. water consumption in the supply chain of inputs).
Impact category	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned (ISO 14044:2006, 3.39). Example: water scarcity, human toxicity, etc.
Infrastructure	Synonym for capital good.

Input	Product, material or energy flow that enters a unit process (ISO 14044:2006, 3.21).
Land use change	Change in the purpose for which land is used by humans (e.g. between crop land, grass land, forestland, wetland, industrial land) (PAS 2050:2011, 3.27).
Life Cycle Assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14044:2006, 3.2).
Life Cycle Inventory	See Water inventory
Precipitation	Liquid or solid products of the condensation of water vapor falling from clouds or deposited from air on the ground.
Primary data	Quantified value of a unit process or an activity obtained from a direct measurement or a calculation based on direct measurements at its original source (ISO 14046:2014, 3.6.1).
Product(s)	Any goods or service (ISO 14044:2006, 3.9). Example: 1 L of milk for consumer consumption.
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 (ISO 14044:2006, 3.28).
Raw material	Primary or secondary material that is used to produce a product (ISO 14044:2006, 3.1.5). Example: Feed crop
Reference flow	Measure of the outputs from processes in a given product system required to fulfill the function expressed by the functional unit (ISO 14044:2006, 3.29). Example: one liter of milk
Reporting	Presenting data to internal management or external users such as regulators, shareholders or specific stakeholder groups (Adapted from: Food SCP RT, 2013).
Runoff	Part of the precipitation which flows towards a river on the ground surface (surface runoff) or within the soil (subsurface runoff or interflow).
Secondary data	Data obtained from sources other than a direct measurement or a calculation based on direct measurements at the original source (ISO 14046:2014, 3.6.2). Secondary data are used when primary data are not available, or it is impractical to obtain primary data. Some emissions, such as methane from manure management, are calculated from a model, and are therefore considered secondary data.
Sensitivity analysis	Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study (ISO 14044:2006, 3.31).
Sewer	Channel, drain for waste water.
System boundary	Set of criteria specifying which unit processes are part of a product system (ISO 14044:2006, 3.32). Examples: Field, Farm, basin/catchment.
Tier	Categorization unit of uncertainty assessment depending on scale of analysis and the data avaibility/sources.
Transpiration	Process by which water from vegetation is transferred into the atmosphere in the form of vapour.
Unit process	Smallest element considered in the life cycle inventory analysis for which input and output data are quantified (ISO 14044:2006, 3.34).

Water body	Entity of water with definite hydrological, hydrogeomorphological, physical, chemical and biological characteristics in a given geographical area. Examples: Aquifers, lakes, rivers, groundwater, seas, icebergs, glaciers and reservoirs. Note 1 to entry: In case of availability, the geographical resolution of a water body should be determined at the goal and scope stage: It may regroup different small water bodies (ISO 14046:2014, 3.1.7).
Water consumption	Water consumption is a form of water use. The term water consumption is often used to describe water removed from, but not returned to, the same drainage basin. Water consumption can be because of evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea. Change in evaporation caused by land-use change is considered [a form of blue] water consumption (e.g. reservoir) (ISO 14046:2014, 3.2.1). Consumptive water use is also used with the same meaning. Water consumption can refer to both blue and/or green water. All water evapotranspired is considered consumed.
Water inventory	Phase of water use assessment involving compilation and quantification of inputs and outputs related to water for products, processes or organizations as stated in the goal and scope definition phase (adapted from 14046 3.3.2). Water inputs refer to both blue and/or green water. In some case water accounting is used as synonym for water inventory.
Water scarcity footprint (WSF)	Metric that quantifies the potential environmental impacts related to water scarcity (based on ISO 14046:2014).
Water use	Use of water by human activity (ISO 14046:2014, 3.2.1).
Water withdrawal	Anthropogenic removal of water from any water body or from any drainage basin, either permanently or temporarily (ISO 14046:2014, 3.2.2).
Metabolic water production	Metabolic water is water formed by a type of metabolism called catabolism in which complex molecules are broken down to release their stored energy, with water as a by-product.
Water Productivity (WP)	Ratio of the benefit to the amount of green and blue water consumed to produce those benefits in a production process (product units: e.g. mass, energy, nutrition per m^3 water). The WP is reported with fractions of green and blue water consumed.
Water Productivity direct (WP direct)	Direct water productivity (in output unit per m3) calculated for a specific process, unit, or stage, including only the direct water consumed (see Direct Water). The goal of this metric is to identify potential improvements in direct water use per output unit of the system assessed as a mean to track its performance.
Water Productivity direct + indirect ($WP_{direct + indirect}$)	Water productivity metric including both direct and indirect water consumption (in output unit per m^3), hence performed on more than one unit processes or life cycle stages. This metric is disaggregated and – optionally - aggregated over different units (potentially located in different regions as the supply chain is included, e.g. imported feed water use would be included in this metric). Such assessment is always accompanied by a water scarcity footprint as per these guidelines.
Water scarcity	Extent to which demand for water compares to the replenishment of water in an area (ISO 14046:2014).

Part 1. Overview and General Principles

1. Introduction

Water is essential to life and a crucial factor in agricultural food production. OECD (2010) reported around 70% of freshwater withdrawal was used by agriculture in the world. During the last century, irrigation played an important role in increasing and stabilizing crop yields and, together with the "green revolution", has therefore led to improving nutritional alimentation in many countries (Rosegrant et al., 2002). The livestock sector is already a major user of natural resources such as land and water, currently using about 35 % of total cropland and about 20 % of blue water for feed production (Opio et al., 2011). Deutsch et al. (2010) estimated that the livestock sector uses an equivalent of 11 900 km^3 of freshwater annually – or approximately 10% of the annual global water flows estimated at 111 000 km^3. Weindl et al. (2017) estimated that for the year 2010, 2 290 km^3 of green water was attributed to feed production on cropland. An initial comparison of a range of different models, confirmed that green water use in global crop production is about 4–5 times greater than consumptive blue water use. Hence, the full green-to-blue spectrum of agricultural water management options needs to be used when tackling the increasing water gap in food production (Hoff et al., 2010).

The expected increase in world population up to 10 billion people will decline the available freshwater resources by half to 6 300 m^3 per capita in 2050 (Lutz et al., 1997; Ringler et al., 2010). The higher world population will lead to an increase in food demand in general by 70 to 90% in 2050 (Rosegrant and Cline, 2003).

There is raising recognition of the increasing competition between users, sectors and use, hence understanding the distribution and demands for freshwater in livestock production is of great importance (Busscher, 2012; Ridoutt et al., 2014; Hoekstra et al., 2012). Water usage for livestock sector should be considered an integral part of agricultural water resource management, considering the type of production system (e.g. grassland-based, mixed crop-livestock or landless) and scale (intensive or extensive), the species and breeds of livestock, and the social and cultural aspects of livestock farming in various countries (Schlink et al., 2010). For example, for every liter of milk produced, a cow needs to drink at least three liters of water (Krauß et al., 2016). For high performing cows, the water requirement corresponds to 150 liters of water per day, and reducing the amount of water consumed is directly correlated to a reduction in milk production. Water intake is mainly related to animal size, age, ration (e.g. type of feed, dry matter content), activity, productivity and temperature (see water inventory chapter). Livestock production is a complex process, characterized by a wide variety of production practices and systems, some of them relying on a broad range of inputs to function.

To contribute to a better insight into the demand for freshwater in a specific region and to improve the performance of individual farms as well as of the whole supply chain, there is a need for water consumption studies to include detailed farm level data regarding climate, agricultural practices and utilization of feed (Jeswani and Azapagic, 2011; Krauß et al., 2015a; Ridoutt and Huang, 2012). Therefore, the LEAP Partnership was created in 2012 with the mandate to compile assessment guidelines that can be recognized and used by all relevant stakeholders. These guidelines are expected to benefit organizations, governments, consumers, farmers, companies, investors and other interested parties worldwide by providing transparency, consistency, reproducibility and credibility for assessing and reporting the water demand of livestock products and hence support the optimization of water resources use and the identification of opportunities to decrease potential impacts from water use in livestock production.

The mandate of the Water TAG was to develop LEAP guidelines on water footprinting to:

1. Provide recommendations for monitoring the water-related environmental performance and water productivity of feed and livestock supply chains over time so that progress towards improvement targets can be measured.
2. Be applicable for feed and water demand of small ruminants, poultry, large ruminants and pig supply chains.
3. Build on and go beyond existing FAO LEAP guidelines.
4. Pursue alignment with relevant international standards, specifically ISO 14040/14044, and ISO 14046.

Guidance from the Water TAG is relevant for livestock production systems including feed production from croplands and grasslands, production and processing of livestock products (cradle-to-gate). It addresses all livestock production systems and livestock species considered in existing LEAP guidelines: Poultry, pigs, small ruminants, and large ruminants supply chains.

1.1 The need for quantitative indicators

There is a need for widely recognized frameworks for the assessment of the performances of livestock and livestock products to mitigate negative impacts on water resources. Historically two methodologies have existed and provided guidelines and indicators for water fooptrinting (Boulay et al., 2013). The present guidelines point towards aspects of these methodologies (Hoekstra et al., 2011 and ISO 14046:2014) in different sections, and with specific recommendations. In this document, potential environmental impacts associated with water use are assessed following the ISO 14046 standard, focusing on water scarcity footprint. Water productivity metrics are described based on the methods of Molden (1997), Molden et al. (1998), Molden and Sakthivadivel (1999), Descheemaker et al. (2010), and Prochnow et al. (2012) as well as guidelines from the Water Footprint Assessment Manual (Hoekstra et al., 2011). The metrics from these two standards go hand in hand in providing an understanding of the pressure exerted by the livestock production sector on the water resources worldwide in order to support potential improvement of its water productivity as well as reduction of its contribution to water scarcity.

Distinction of water use efficiency and water productivity

Water use efficiency is different than water productivity as water use efficiency refers to ratio or percent of water effectively used by the plant, e.g. water use efficiency is 80% if 10 mm of irrigation water is added to a crop while 8 mm are used through the root water uptake and 2 mm are lost by drainage below the root zone, or via unproductive soil evaporation. Both the numerator and denominator have the same units. Water productivity is the metric used in this document and refers the ratio of the benefit to the amount of water consumed to produce those benefits, e.g. it is 50 kg grain per 1 m^3 of water.

1.2 Scope and objective of the guidelines

1.2.1 Scope of the guidelines

This document presents principles, requirements and guidelines of water use assessment associated with livestock production and products. The term "shall" is used to indicate what is required for an assessment to conform to these guidelines. The term "should" is used to indicate a recommendation, but not a requirement. The term "may" is used to indicate an option that is permissible or allowable. The task of conducting a water use assessment should involve stakeholders representing the range of livestock production and related sectors for the given study. Their participation improves data quality as well as dissemination.

In this document, water use assessment includes:

- Chapter 5.1 "Water scarcity impact assessment": The assessment of the environmental performance related to water of a livestock-related system by assessing potential environmental impacts of blue water consumption, following the water scarcity footprint according to the framework provided by ISO 14046; and
- Chapter 5.2 "Assessment of water productivity": The assessment of the water productivity of the system (for e.g. performance tracking purposes), following the methods of Molden (1997); Molden et al. (1998), Molden and Sakthivadivel (1999), Descheemaker et al. (2010), and Prochnow et al. (2012) and Water Footprint Assessment Manual 2011 (Hoekstra et al., 2011).

The inventory Chapter 4 "Inventory" is relevant to both types of assessment.

Water-related aspects addressed in the guidelines

These guidelines cover all quantitative aspects associated with water use: Water consumption (inventory flows, water productivity and contribution to water scarcity. However, water quality-related aspects are outside the scope of this document. They are (partially) covered in the companion LEAP document detailing Nutrient Cycles Accounting. No guidance is provided by LEAP yet on (eco)toxic impacts. An assessment following this document therefore has a more limited scope in comparison with a comprehensive water footprint (as per ISO 14046) and this should be acknowledged by the stakeholders. LEAP works closely with Sustainable Development Goals (SDG) and has the aim to accelerate the agenda until 2030. SDG 6.4 states "By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity".
This document does not provide support towards the assessment of comprehensive environmental performance, nor to the social or economic aspects of livestock supply chains (animal productivity and welfare). Considering that water footprinting is still an evolving science, the guidelines are expected to be continually revised based on reliable data and sound methodologies.

Application

Some flexibility in methodology is desirable to accommodate the range of possible goals and special conditions arising at different levels within the livestock sector, while still providing guidance that will support greater consistency in common areas and objectives. This document strives to reach a pragmatic balance between flexibility and consistency across scale, geographic location, and project goals. The water scarcity impact assessment is suitable for the assessment of the water-related environmental performance. The assessment of water productivity suits an efficiency assessment. However, to avoid misguided decision or misleading information being conveyed, if the overall water productivity metric of a production system is incorporating indirect water use (e.g. from feed produced at a different location), it shall be accompanied by the water productivity metrics of direct water flows separately for each stage of the system, as well as the water scarcity footprint of the analyzed system, in order to satisfy the recommendations of these guidelines.

Use of the Water Productivity metric

An overall water productivity metric of a production system incorporating indirect water use shall be accompanied by the water productivity metrics of direct water flows for each stage of the system, as well as the water scarcity footprint of the analyzed system.

To avoid confusion potentially caused by the use of terms with different definitions outside this document, the following terminology is set (Table 1).

Table 1: Terminology used in the LEAP Guidelines on water use assessment

Terms used in this document	Meaning
Green water	Precipitation that is stored as soil moisture and eventually transpired or evaporated
Blue water	Freshwater flows originating from runoff or percolation, contributing to freshwater lakes, dams, rivers and aquifers. A special case exists with respect to water from flooding, where the moisture contributed to the soil is considered blue water.
Blue water inventory	All blue water inputs and outputs occurring over the life cycle of the product system
Green water inventory	All green water inputs and outputs occurring over the life cycle of the product system
Water inventory	Phase of water use assessment involving compilation and quantification of inputs and outputs related to water for products, processes or organizations as stated in the goal and scope definition phase" (adapted from 14046 3.3.2). Water inputs refer to both blue and/or green water. Water inventory results shall not be reported as a water footprint (which requires impact assessment).
Water scarcity footprint	Metric that quantifies the potential environmental impacts related to water scarcity
Water productivity	Ratio of the benefit to the amount of water consumed to produce those benefits in a production process (product units per m^3 water)

Terminology use of blue and green water

The TAG recognizes that the terminology "blue water" and "green water" is not recognized by all, and that other wordings exists to refer to these different types of water flows. Although the terms blue and green water are used in this document, their adoption is not necessary for the application of these guidelines.

1.2.2 Objective of the guidelines

The objective of the Water TAG was the development of guidelines that can support management solutions through improvement over time via comparison of practices in livestock supply chains. Sound recommendations were expected on water use assessment that adequately capture the specificities of livestock production systems. Building on existing standards and methods, the activity focused on building global consensus on the general topic of water footprinting of livestock supply chains. More specifically, the objective of these guidelines is to provide comprehensive recommendations to assess water scarcity footprint and water productivity in the global livestock sector, applicable anywhere in the world, based on existing methodologies. The animal health and welfare, although not assessed in this document, should be an overarching objective over the optimization of water use in livestock. Water use should be optimized without negative influence on animal welfare.

This assessment goes through different metrics which provide guidance on different aspects of water-related issues, opening the door to a wide set of solutions. The most demanding step is the water use inventory, which collects the essential information for the subsequent quantification of the potential environmental impacts (on human and ecosystems) from all interactions of the livestock production system on the water resource and its cycle, as well as the efficiency of water use in the system, via the water productivity metric. The interpretation of the results obtained in this assessment allows for minimizing potential environmental impacts while optimizing the productivity of the water use.

The guidelines are structured into seven chapters. After the first chapter (Introduction) in which the scope of the document is presented, e.g. process of guidelines and environmental impact categories addressed in the guidelines, the second chapter (Scope) gives information on the elaboration of the scope of the water use study itself. The third chapter (Data quality - data sources, databases) describes data types, data quality and resulting uncertainties. The information provided here points to other documents and handling of missing information. In Chapter 4 (Water use inventory), methods for addressing water use inventory are listed, system boundaries are shown, and relevant water flows are described. In Chapter 5 (Assessment) two water scarcity impact assessment methods are described and recommended followed by water productivity metrics. Chapter 6 (Interpretation of results) describes the interpretation of the results to provide information on which points on the production chain the process can be improved such that impacts are minimized, and resource use efficiency is improved. Chapter 7 (Reporting) provides information on reporting the results of the assessments.

Part 2. Methodology

2. Scope

2.1 Goal of the water use assessment

2.1.1 Goal of the water scarcity impact assessment

The goal of the water scarcity impact assessment is to evaluate the contribution of an activity (e.g. livestock production) to water scarcity, and its related potential environmental impacts from deprivation of other human or ecosystem water users. As scarcity is an issue with large spatial and temporal variability, those aspects need to be quantified and hence such potential impacts are not represented by the volumetric measures only: They need to be put in context of the local water scarcity with the use of a characterization factor quantifying it (as per section 5.1.4). Assessing the different contributions of water consumption of a system over the entire supply chain, allows for identifying the most impacting life cycle stages (from cradle-to-gate) and hence look for solution where the benefit for the environment can be the greatest.

Apart from understanding the magnitude and distribution of potential environmental impacts associated with water scarcity, a water scarcity impact assessment provides a water scarcity footprint (as per ISO 14046:2014), which can help in environmental impact reduction, communication and stakeholders engagement, water management and stewardship, sustainability strategy and marketing of more sustainable solutions. Examples of such goals are listed in Table 2) below:

Table 2: Possible goals of water scarcity impact assessment such as water scarcity footprint (extracted from Vionnet et al. (2017)).

General objectives	Examples of more detailed objectives
Resources efficiency and environmental impact reduction	- Product development and optimization including environmental criteria - Organizational target to reduce direct and/or indirect water footprint - Identify hotspots in terms of water footprint throughout a product life cycle or an organization to prioritize investments
Communicate and engage with stakeholders	- Manage the license to operate of an existing production site - Engage with local authorities to contribute to a watershed management plan - Communicate the pressure on water of an organization to its investors
Water management and stewardship	- Risk assessment and management at site or organizational level - Contribute to reducing and compensating a product or organization environmental impact
Sustainability strategy	- Setting target and priorities of water reduction at organizational level - Identify the most important stage in the life cycle of a product to develop innovative management solutions - Complement a materiality assessment
Marketing of more sustainable solutions	- Marketing support for more sustainable solutions, focusing on aspects of water - Using information for business related activities and information for different markets

2.1.2 Goal of the water productivity assessment

Water productivity is the ratio of the net benefits from livestock to the amount of water consumed to produce those benefits. The benefits can either be measured as the physical agricultural outputs or the economic value of these outputs. The amount of water consumed is defined as water removed from, but not returned to, the same drainage basin. Water consumption can be because of evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea. An intended application of the water productivity assessment is to assist farmers in understanding the water flows in their farms and in optimizing water use by agronomic measures and farm management (Table 3).

We distinguish direct and indirect water productivity based on direct water consumption (or operational use) and indirect water consumption (supply chain use). Direct water productivity (WP_{direct}) includes only water consumed directly in the production system. In these guidelines, direct WP is used to identify improvements in direct water productivity of a product as a mean to track the performance of the system's foreground. Indirect + direct WP ($WP_{direct+\ indirect}$) includes additional water consumed indirectly in the production system (e.g. off-farm feed production) as water consumed in a different location and accompanies the individual direct WP when considering supply chain inputs into the production system. The goal of this metric is to quantify the use of water in the assessed production system by considering direct and indirect water consumption per functional unit of product. However, as the $WP_{direct+\ indirect}$ metric does not inform on potential issues associated with the different water uses, as these depend on their individual local context based on their geographical location, it shall always be accompanied by the individual components of direct WP as well as the water scarcity footprint (WSF) of the analyzed system, in order to prevent misguided decision based on $WP_{direct+\ indirect}$ which may not represent an environmental improvement (i.e. if a higher productivity is associated with a higher water scarcity footprint for example). A combination of the WP metric and WSF may show potential to improve the overall performance of the system related to water consumption.

Table 3: Goals of the water productivity assessment (modified from Ran et al., 2016; Giordano et al., 2017) and associated method

Goal	Scale	User	Method
Assessing energy conversion, biomass or harvestable yield from a particular feed crop or cultivar	Crop	Plant physiologists, farmers	WP_{direct}
Assessing energy conversion, biomass or harvestable yield from a particular feed cropping system	Field	Soil and crop scientists, farmers	WP_{direct}
Assessing yield or economic return from a farm´s livestock production to assist farmers in understanding the water flows in their farms and in optimizing water use by agronomic measures and farm management at one specific farm location.	Farm	Farmers, agricultural advisers , processing industry, water manager	WP_{direct}
Assessing yield or economic return from a farm´s livestock production to assist farmers in understanding the water flows in their farms and resulting effects in optimizing water use by agronomic measures and farm management at the specific farm location and at potentially different regions.	Farm	Farmers, agricultural advisers , processing industry, water manager	$WP_{direct + indirect}$, (+WSF, + WP_{direct})
Comparison of different livestock production systems to identify potentials to increase water productivity (for smallholders in water-scarce areas and areas with poor water resource development)	Farm, river basin, watershed, community	Farmers, agricultural advisers, water manager	WP_{direct} or $WP_{direct + indirect}$, (+ WSF, + WP_{direct})

2.2 Scope of a water use assessment following LEAP Guidelines

2.2.1 Characterization of livestock production systems

Livestock provide a wide range of products and services. The list of products includes meat, milk, fibre (e.g., wool, angora), skins and hides. In addition, livestock may also provide services such as income generation, transport, draught power, manure for soil fertility improvement and energy production, asset accumulation and social security. Production systems vary greatly from place to place in scale, degree of specialization, practices and across agro-climatic settings. Description of the livestock production systems under investigation is essential as resource utilization in general, and water use in particular, is closely connected to the production method. This knowledge is also imperative for the development of improvement strategies. Feed represents a major component of almost any livestock supply chains (see Chapter 4.3 Defining feeds or feeding stuff). Correspondingly, feed production often embodies the largest segment of water use in livestock production and thereby the major contributor to environmental impacts related to water scarcity. Hence, identifying origin, types and amount of feedstuff used for livestock feeding and determining water use associated with feed production is of paramount importance to livestock water use assessments.

Many farms present a mixture of animal species (e.g. sheep, cattle, buffalo, poultry and swine) which are often farmed together. Where possible, it is recommended to separate activities of the farm system for the different animal species where specific uses can be defined (e.g. use of summer forage crops for beef and dairy cattle, portion of the year fed in confinement, confined vs free range swine production). To estimate water use, the volume and nature of the water used with each of the livestock species shall be determined. This would include summing all of the consumptive uses as described in chapter 2.8 for each of the livestock species in a mixed production system. For grazing livestock (as well as non-grazing), water consumption shall be estimated based on the total feed intake for each of the different animal species and allocation based on the relative feed intake between species.

2.3 System boundary

The system boundary shall be clearly defined and include all life cycle stages from raw material extraction to the gate of the production phase (cradle-to-gate), either the farm gate or the processing gate. Alternatively, a complete cradle-to-grave (life cycle) assessment of water use would also include distribution, consumption and product end-of-life management stages.

Three main system boundaries have been identified: (1) cradle-to farm gate; (2) cradle-to-processing gate; and (3) cradle-to-final-use. Figure 1 depicts a typical livestock life cycle including all phases that support the livestock activities such as pesticides or herbicides and fertilizer production, fuel, seeds, etc., as well as co-products. Green water is involved at the farm scale in feedstock production (pasture, roughages and grains). Blue water is involved at the primary processing state in feedstock production (roughages, grains, concentrates), as drinking and service water (e.g. for cleaning) and as water to produce other inputs (e.g. electricity). Blue water is involved at primary processing stage as hydroelectricity and as service/processing water at each process (orange blocks). When energy along the supply chain is sourced from biomass, a green water component can be involved (Vanham, 2016). Substantial water losses can occur in water supply systems both on and off-farm, and these must be accounted for in the water use inventory, as consumption or returned flows, depending of the context.

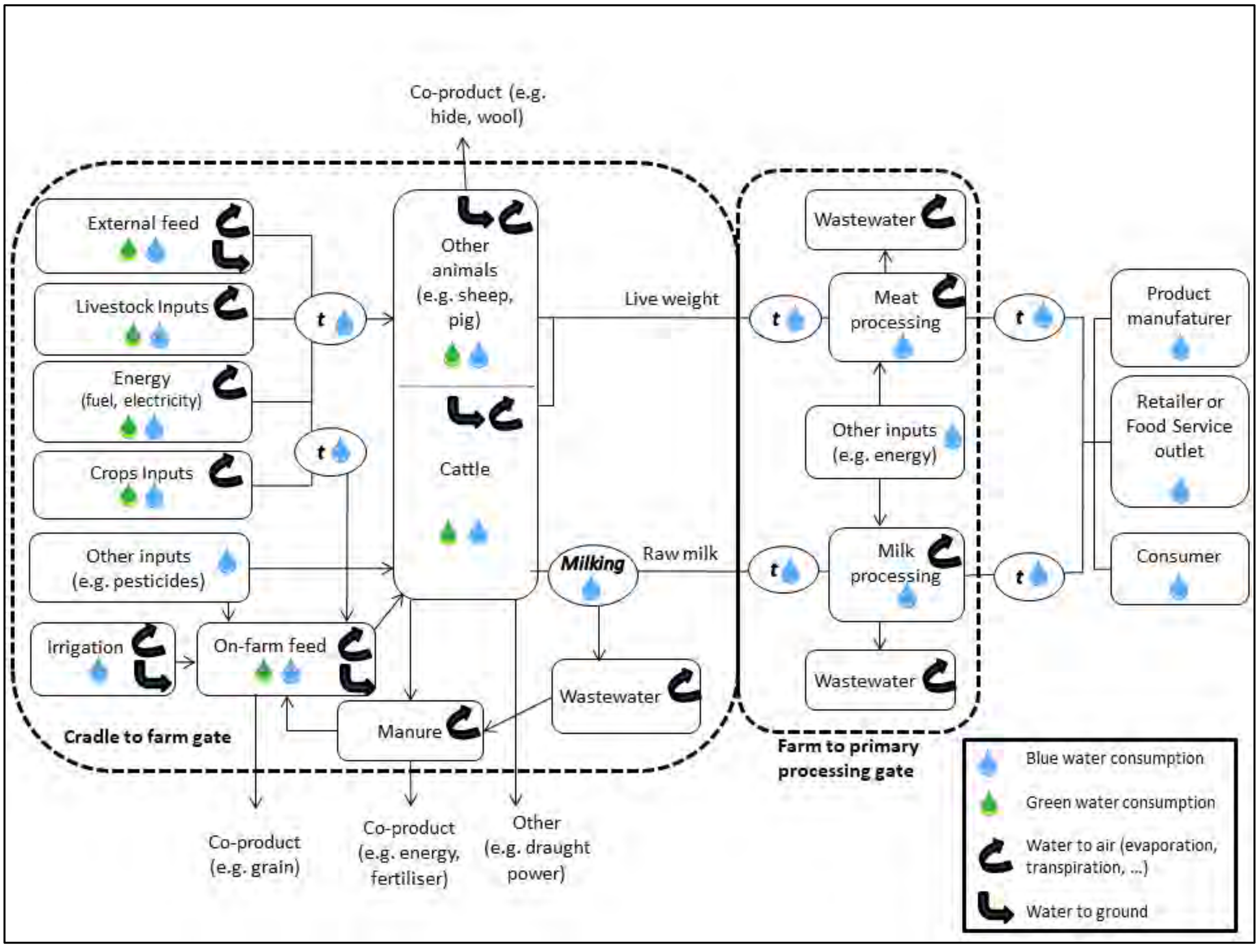

Figure 1: System boundary and main water flows of livestock production systems: Cradle to processing gate, t: transport.

The overall system boundary covered by the above-mentioned LEAP Guidelines represents the cradle-to-primary processing stages of the life cycle of the main products from livestock. It covers the main stages of the cradle-to-farm-gate, transportation of animals to primary processing facilities, and then to the primary processing gate (e.g. to the output loading dock). Sections 7.2 of each specific LEAP Guidelines depict the modular approach followed by dividing the production system into modules that relate to different life cycle stages. Main stages can be summarized into feed production (including feed processing, milling and storage), animal production (including animal breeding, primary production, feedlot/finishing) and primary processing. The feed stage is covered in detail in the associated LEAP Animal Feed Guidelines and encompasses feed production from the cradle-to-animal's-mouth for all feed sources (including raw materials, inputs, production, harvesting, storage and feeding); other feed-related inputs – such as supplements for any specific dietary requirement – are covered in detail in each LEAP Guidelines (Sections 11.2).

2.4 Functional units and reference flow

The system of interest is water use in the livestock production and supply chains. The concepts of functional units (FU) and reference flows (RF) refer to input and output exchanges in the production system under study. While a functional unit describes the quantified performance of the function(s) delivered by a system (e.g. provide 1000 l of bulk milk ready for packaging), reference flows refer to the "measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit" (ISO 14044: 2006), e.g. 1000 l of bulk milk. Both functional units and reference flows shall be clearly defined and measurable.

In livestock production systems, FU and RF are specific to each of the species and differ for the nature of the final product used. Where meat is the product, it is necessary to differentiate between Live Weight (LW) of the animal (at the farm gate) and Carcass Weight (CW) or Dressed Weight (DW) (at abattoir gate); the latter refers to the final weight of the animal after the internal organs, head as well as the inedible portion (e.g., tail, legs, skin, feathers etc.) have been removed. LEAP Guidelines detail the FU and RF for each specific Livestock species especially when the final product could be different from meat. Table 8.1 in LEAP Guidelines on Pig Supply Chain provides recommendations for the choice of functional units/reference flows; Table 2 (pg. 40) in LEAP Guidelines for Large Ruminants illustrates the Recommended Functional Units/Reference Flows for the three different main product types from large ruminants (meat, milk, draught power) according to whether it is leaving the farm or primary product processing gate; Table 1 (pg. 28) of LEAP Guidelines on Poultry reports the Recommended Functional Units/Reference Flows for different main product types of the sector (meat and egg); Table 1 (pg. 26) in LEAP Guidelines on Small Ruminants illustrates the Recommended Functional Units/Reference Flows for the three different main product types from large ruminants (meat, milk, fibre) according to whether it is leaving the farm or primary product processing gate. Commonly used functional units and reference flow of different livestock product system are listed in Appendix 1, and commonly used models are listed in Appendix 2).

2.5 Co-product allocation

The ISO 14044 and ISO 14046 standards give the following guidelines about handling multi-functional production:

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

a) 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; or

b) Expanding the product system 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.

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 (e.g., in proportion to their economic value).

Please consult other FAO-LEAP guidelines (LEAP 2016a; 2016b; 2016c; 2016d; 2018) regarding the assessment of the environmental performance of a livestock species (i.e., pigs, poultry, small ruminants, large ruminants) to get details about species-specific recommendations on multi-functional processes and allocation.

2.6 Geographical and spatial coverage and distribution of the study

Freshwater is an increasingly scarce resource whose availability varies widely over temporal and spatial scales. According to the scope of the analysis to perform, spatial and temporal scales of the study have to be addressed accordingly. Temporal and spatial representativeness of data include time and method of collection (primary or secondary data), time span and geographical areas. Table 3 presents the different levels of details, scales, data sources and potential applications of a water productivity assessment. The spatial and temporal resolution for water scarcity footprint will likely be dictated by the impact method used, however both methods in this document (Chapter 5.1.4) recommend monthly and watershed scale. When such level of resolution is not available (e.g. for background data), larger aggregation (such as annual and country level) may be performed if supported by the impact method. The result of a water scarcity footprint however provides a value representing the different contributions to local water scarcity aggregated at the global level.

The smallest spatial resolution considered for a water use assessment is the watershed (~100-1000 km²), but may go as low as the field level (<0.5 km²) for a water productivity assessment. In the latter case, it is necessary to account for water use per farm. Where large differences in water use occur across seasons or months, this should be considered.

2.7 Temporal Resolution

2.7.1 Water availability

Water availability fluctuates within and across years, so that water demand varies in time as well. When undertaking a water use assessment, one should be explicit regarding the period of data used – since the period will affect the outcome – by choosing to assess water use for a specific year or several years, or alternatively by choosing to perform the assessment for a given climatic period, typically 30 years, or at a minimum of 5 years given the existing climate (IPCC, 2001).

2.7.2 Feed production

According to FAO LEAP animal and feed supply chains, the feed production stage does not only have a physical boundary, but also a time boundary. According to the Chapter 8.4.2 the time boundary is defined by the length of the production cycle that is being examined. For multiple harvests per year of the same crop, it may be decided to set the time boundary between two consecutive growing seasons (years), but for a more detailed assessment, the time boundary may be set between two production cycles of the same crop. Then the boundary is set at the moment when the crop or harvest (of the same crop) has been removed and activities for the new crop or harvest (of the same crop) will start. All water flows related to activities for, or residues of, the previous crop or harvest will be allocated to that previous crop or harvest (LEAP, 2016d).

Thus, the reference period comprises the period between tillage and harvest of the main crop plus the period of preceding fallows and/or cover crops. The reference period for grassland is the calendar year as the land is covered with the same type of vegetation permanently. Thus, the reference period in crop production is not uniform for the whole farm, but varies from field to field (Prochnow et al., 2012).

In the section “Dealing with variability in crop production cycles” of the LEAP (2016d) it is stated that the cultivation data shall be collected over a period sufficient to provide an average assessment of the resource use associated with the inputs and outputs that will offset fluctuations due to seasonal differences. Recommendations for annual crops (3 years), perennial plants (steady situation resp. a three-year rolling average), and for crops grown and harvested in less than one year (specific time for the production of a single crop from at least three recent consecutive cycles) are given there. The selected years should be able to consider as much as possible the climate variability in the area.

2.7.1 Animal production

Section 8.4.4 of FAO LEAP animal and feed supply chains defines the time frame when it comes to conduct a study. A minimum 12-month period for all livestock species is recommended since it covers all live stages of the animals along the production chain. In addition, the study shall use a representative herd population (at steady state and inclusive of a population balance) representative of all animal classes and ages present over the 12-month period required to produce the given mass of product (see FAO LEAP animal guidelines, LEAP 2016a; 2016b; 2016c; 2018).

2.8 Water consumption (feed production; drinking; servicing; processing)

Depending on the scope of the water use assessment performed, if it includes a water productivity assessment (e.g. WP_{direct}) the water consumption data considered may be of more limited scope, but the general recommendation is to assess both direct and indirect water consumption, since the indirect water consumption may be much larger than the direct water consumption. In contrast to direct water consumption which implies the direct use of water in the production system under consideration (or foreground process), indirect water consumption relates to water consumed by the supply chain (or background processes).

Direct water for livestock includes:

- On-farm irrigation water (feed production);
- Drinking water – at farm stage both for primary production and for the finishing stage;
- Service and processing water – at farm, finishing and slaughtering stages (including cleaning and cooling);

Indirect water for livestock includes:

- Irrigation water of purchased feed;
- Electricity production water requirements – water used (consumed) to produce electricity. Electricity is used all along the production chain: Feed production (including the production of fertilizers and pesticides), primary production, finishing and slaughtering stages.
- Water required to produce fertilizers, pesticides, etc.

3. Data quality - data sources, databases

3.1 General principles for Data Quality

The compilation of the inventory data shall be aligned with the goal and scope of the water productivity and water scarcity impact assessment. The LEAP guidelines are intended to provide users with practical advice for a range of potential study objectives of the water use assessment. This is in recognition of the fact that studies may wish to assess water use ranging from individual farms, to integrated production systems, to regional or national, or sector levels. When evaluating the data collection requirements for a project, it is necessary to consider the influence of the project scope. In general, these guidelines recommend collection of primary data for foreground processes, those processes generally being considered as under the control or direct influence of the study commissioner.

However, it is recognized that for assessments with a larger scope, such as sectorial analyses at the national scale, the collection of primary data for all foreground processes may be challenging. In such situations, or when a water use assessment is conducted for policy analysis, foreground systems may be modelled using data obtained from secondary sources, such as national statistical databases, peer-reviewed literature or other reputable sources. The data recorded in relation to this water use inventory shall include all water use processes occurring within the system boundary of that product.

As far as possible, primary water use inventory data shall be collected for all water use associated with each life cycle stages included within the defined system boundaries. For processes where the practitioner does not have direct access to primary data (i.e. background processes), secondary data may be used. When possible, data collected directly from suppliers should be used for the most relevant products they supply. If secondary data are more representative or appropriate than primary data for foreground processes (to be justified and reported), secondary data shall also be used for these foreground processes (e.g. the economic value of products over 3 to 5 years).

When performing a water use assessment, it shall be demonstrated that the following "water inventory principles" are considered (adapted from ISO14044):

3.1.1 Representativeness

Qualitative assessment of the degree to which the data reflects the true population of interest. Representativeness covers the following dimensions:

a) Temporal representativeness: Age of data and the length of time over which data was collected;

b) Spatial representativeness: Geographical area from which data for unit processes was collected to satisfy the goal of the study.

c) Technology representativeness: specific technology or technology mix; Precision: measure of the variability of the data values for each data expressed (e.g. standard deviation).

3.1.2 Source, precision, completeness of data

a) Source: Source of the data (e.g. reference or measurement);

b) Precision: Measure of the variability of the data values for each data expressed (e.g. standard deviation);
c) Completeness: percentage of data (e.g. of freshwater input) that is measured or estimated

3.1.3 Consistency, reproducibility and uncertainty

a) Consistency: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
b) Reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study.

3.2 Data types and sources: data identification

Two types of data may be collected and used in performing water use assessments: Primary and Secondary.

3.2.1 Primary data

Primary data is defined as directly measured or collected data representative of processes at a specific facility or for specific processes within the product supply chain. Primary data refers to information which is directly collected as part of the current study, while secondary data refers to data which may be available in existing lifecycle inventory databases or maybe collected from published literature. The LEAP guidance for the poultry sector (LEAP, 2016c) includes a data collection template as one of the Annexes.

3.2.2 Secondary data

Secondary data is defined as information obtained from sources other than direct measurement of the inputs/outputs from processes included in the life cycle of the product (PAS 2050:2011) available in existing life cycle inventory databases or collected from published literature. Secondary data are used when primary data of higher quality are not available, or it is impractical to obtain them. Water use for crops intended as feed for livestock is calculated from a model, and is therefore considered secondary data.

3.2.3 Approaches to handle missing data

Data gaps exist when there is no primary or secondary water use data available that is sufficiently representative of the given process in the product's life cycle. Gaps in life cycle inventory (LCI) data can result in inaccurate and erroneous results (Reap et al., 2008). A two-step procedure can be used to compile required datasets; (1) Screening, and (2) Compilation. A screening step could be conducted by using readily available specific and/or generic datasets to identify the most sensitive and influential, but uncertain data inputs, i.e. the 'main data inputs'. In the compliation step, efforts shall be made to make direct measurements and/or best estimates of the main data inputs. The main data inputs must meet at least the 'good' data quality requirements. Data should be obtained from databases made in compliance to recognized international reference data systems: e.g. ILCD (2010).

3.2.4 Data quality

Practitionners shall assess data quality by using data quality indicators as described below. Generally, data quality assessment can indicate how representative the data are as well as their quality. Assessing data quality is important for a number of reasons: improving the inventory's data content, proper communication and interpretation of results, as well as informing users about the possible uses of the data. Data quality refers to characteristics of data that relate to their ability to satisfy stated requirements (ISO14040: 2006a). Data quality covers various aspects, such as technological, geographical and time related representativeness, as well as completeness and precision of the inventory data.

For significant processes, practitioners shall document the data sources, the data quality, and any efforts made to improve data quality.

3.2.5 Guidance to assess primary data

In general, primary data shall fully feasible, be collected for all foreground processes and for the main contributing sources of environmental impacts. Foreground processes are defined as those processes under the direct control of, or significantly influenced by, the study commissioner.

3.2.6 Guidance to assess secondary data

Secondary data refers to life cycle inventory and other generic data sets generally available from modelling processes, existing third-party databases, government or industry association reports, peer-reviewed literature, or other sources. Secondary data should only be used for foreground processes if primary data are unavailable, if the process is not environmentally significant, or if the goal and scope permit secondary data from national databases or equivalent sources. All secondary data shall satisfy the following requirements:

- They should be as current as possible and collected within the past 5-7 years; however, if only older data is available, documentation of the data quality is necessary and determination of the sensitivity of the study results to these data must be investigated and reported.
- They should be used only for processes in the background system. When available, sector specific data shall be used instead of proxy LCI data.
- They shall fulfill the data quality requirements specified in these guidelines.
- They may only be used for foreground processes if specific data are unavailable or the process is not environmentally significant. However, if the quality of available specific data is considerably lower and the proxy or average data sufficiently represents the process, then proxy data shall be used.

3.2.7 Data Quality Indicators

An evaluation of the quality of these datasets for use in the specific assessments should be made and included in the documentation of the data quality analysis (Table 4). Such quality assessment can also serve as input to calculate uncertainty of the data in absence of reported uncertainty, which is often the case (section 3.3).

Table 4: Overview of data quality criteria.

Quality level	Quality rating	Geographical representativness	Temporal representativeness (number of years)	Completeness (measured as %)	Reproducibility (measured as (Yes/ No)	Uncertainity (High/low)
Very good	1					
Good	2					
Fair	3					
Poor	4					
Very Poor	5					

3.3 Data uncertainty

3.3.1 Data uncertainty assessment methods

Data with high uncertainty can negatively impact the overall quality of the water use inventory. The collection of data for the uncertainty assessment and understanding uncertainty is crucial for the proper interpretation of results and their reporting and communication.

Uncertainity in water use assessments could be introduced by two main factors, (1) uncertainity in data inputs 'i.e. the parameter uncertainty', and (2) choice of the model including system boundaries, allocation choices, spatial and temporal representativeness and other assumptions 'i.e. the model uncertainty'. The parameter uncertainty should be quantified by using the appropriate statistical techniques, e.g. World Resources Institute / World Business Council for Sustainable Development (WRI/WBCSD, 2011) has published additional guidance on quantitative uncertainty assessment which includes a spreadsheet to assist in the calculations, and the model uncertainty should be assessed using a scenario analysis. Uncertainty can be assessed two different ways (Pfister and Scherer, 2015):

- Analytically, e.g. by Taylor series expansion; used to combine the uncertainty associated with individual parameters from a single scenario.
- Numerically, e.g. by a Monte Carlo simulation; a well-known form of random sampling used for uncertainty analysis, a commonly used tool in commercial life cycle assessment software.

3.3.2 Uncertainties related to benchmarking

Benchmarking is a standardized method for collecting and reporting model outputs in a way that enables relevant comparisons, with a view to establishing good practice, diagnosing problems in performance, and identifying areas of strength. It can form a basis to compare environmental performance related to water in certain regions or even at field level to certain reference levels and can form a basis to formulate improvement targets that are aimed to decrease water consumption and its associated potential impacts per unit of product. Water consumption of crops varies enormously across regions and within regions (Finger, 2013; Siebert and Döll, 2010; Perry, 2014). Although global benchmarks are not yet within reach, metrics in these guidelines could be used for performance tracking.

3.3.3 Minimize uncertainty using a tiered approach

A water use assessment (both at the inventory level as well as the water scarcity impact assessment) requires accurate quantification of both water use data in the production process and local hydrological data on water availability, water use and environmental flow requirements in the production area. Both primary and secondary data may contain some level of uncertainty (lack of accuracy and precision) depending on their measurement and/or estimation methods and models used. Water use and hydrological information are generally estimated/modelled for regional and global scale assessments, where direct measurements are difficult, time-consuming and expensive. Exisiting global and regional databases, often used in different types of water use assessment studies for livestock production and supply chains, are generally based on estimates and/or limited in their direct measurements at higher spatial and temporal scales. This poses increased uncertainty if global and regional databases are used for local catchment or field level water use assessments for livestock production. In order to minimize this uncertainty a tiered approach is suggested as follows (Table 5: Table A. 13) to match the scale of analysis and the data avaibility/sources with the analysis conducted (Hoekstra et al., 2011). The application of Tier 2 and 3 level approaches will provide more accurate estimates and sound knowledge base, but at a cost of greater effort and more resources.

Table 5: Tiered approaches of uncertainty assessment

Tier Level	Spatial Scale	Temporal Scale	Data sources/methods
Tier 1	• Global level • Regional level (Agro-climatic zones)	Average annual or monthly	• Global and regional databases/models • Peer-reviewed papers and technical reports • Global and regional maps
Tier 2	• Catchment level • Water management zones	Annual or monthly	• Catchment specific databases/models • Peer-reviewed papers and technical reports
Tier 3	• Farm level • Field level	Annual, monthly or daily	• Direct measurements (i.e. primary) data • Use of detailed calibrated and validated model (if direct measurements are not possible) • Water meters • Expert consultations

3.3.4 Data proxies

If proxies are used in case of data gaps, this shall be recorded in the study report. The user can choose among the following ranked options as proxies. If proxy data are used, the impact of these data on the uncertainty of the model shall be determined and discussed in the study. The following options can be used to identify proxies:

- ➢ If the country of origin is known:
  - Use the same ingredient from another country with similar blue water availability and climate zones as proxy
  - Use similar crop from the same country conditions as proxy
  - Use a product group average from the same country as proxy (as an example, if data are missing for sorghum from Argentina, another cereal with similar water requirement in Argentina can be used as proxy)
- ➢ If the country of origin is not known:
  - Use the regional or world average as proxy (such as production-weighted arithmetic mean)
  - If not available, use the product group average as proxy

4. Water inventory

4.1 Overview

One of the first steps required for the livestock water use assessment is to gather proper knowledge of the animals, their populations and the conditions in which they are managed. Water is essential for livestock health and production. Water requirements vary considerably depending on the species of the animal, breed, age, growth rate, pregnancy, production status, activity, feed type and weather. Water requirement and intake are also highly affected by climatic factors particularly environmental temperature. Up-to-date steps to calculate water requirements of livestock species (as influenced by physiological status and environmental conditions) can be obtained from standard scientific guidelines detailing nutrient requirements of a livestock species. For example, the latest equations to determine the drinking water requirement of various classes of beef cattle are presented in a document released recently by NAS (2016).

As with any inventory exercise the steps involved are: Data collection, using the principles as outlined in Chapter 3; recording and validation of the data; relating the data to each unit process and functional unit (including allocation for different co-products); and aggregation of data, ensuring all significant processes, inputs and outputs are included within the system boundary.

The water use inventory shall be in compliance with ISO 14046 standards.

4.2 Production systems

Large ruminant production systems

Cattle and buffalo are the main economically important large ruminants in the world with about 1.5 billion and 195 million heads, respectively, in 2014. Large ruminants are raised under a wide variety of agro-ecological zones with varied climatic, edaphic and topographic conditions that determine the quantity, quality and composition of the livestock feeds and thereby productivity. Detailed classification of large ruminant production systems and the description of the supply chains of beef and dairy cattle are provided in the FAO-LEAP document entitled “Environmental performance of large ruminant supply chains: Guidelines for assessment” (LEAP, 2016a).

Small ruminant productions systems

Globally, there were 1.2 billion sheep and 1 billion goats in 2014. About 83% of the small ruminants in the world are found in Africa and Asia. Sheep and goats play valuable multi-functional roles, especially in low-input farming systems. Small ruminant production presents diverse systems with different intensities and production objectives. The major regional and global small ruminant production systems and supply chains are given in a FAO-LEAP document entitled “Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for quantification” (FAO, 2016b).

Pig production systems

The world population of pigs in 2014 was about 987 million heads of which Asia accounted for 60% of the total. Several pig production systems can be identified in a given country or region, from the simplest systems (e.g., backyard production systems) which require a small amount of investment, to large-scale commercial pig farms. Description of common pig production systems and supply chains is provided in a FAO-LEAP document entitled "Environmental performance of pig supply chains: Guidelines for assessment" " (FAO, 2018).

Poultry production systems

Poultry production systems may be classified based on production scale, housing, feeding system, genotype and health provision. The FAO-LEAP document entitled "Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment" may be consulted for additional details about poultry production systems and supply chains (FAO, 2016c).

4.3 Defining feeds or feeding stuff

The feed is any single or multiple materials, whether processed, semi-processed or raw, which is intended to be fed directly to animals (FAO/WHO, Codex Alimentarius CAC/RC 54-2004, amended in 2008). Livestock feeds provide the basic nutrients required for animal production, including proteins, amino acids, minerals, vitamins and other micronutrients. The animal feed depends on a number of sources for feed material. Crops grown as feed for farm animals can be classified as grains (e.g. wheat, barley, corn, oats, sorghum, and millet), oilseed crops, and feed produced as by-products (e.g. cotton seed cake) or as forages (e.g. grasses, legumes, silages). The mix of livestock production and feeding systems that utilize concentrate feeds varies across the different farming systems and geographical regions of the world. The animal feed sector depends on a number of sources for feed material including the crop production sector, the food industry, products deriving from the slaughter and processing of livestock, the marine industry, and biofuels. Consequently, feed supply chains vary greatly depending on the specific raw material and its intended uses. Broadly, a distinction can be made between ruminant and monogastric species; with the latter being largely dependent on feed materials from crop production such as grains (cereals & legumes crops), oilseed crops (canola, cotton, soybean etc.) and household waste, and the former on roughages such as grasses, plant leaves and forage feedstuffs.

Water use assessment on farm scale

Water use assessment on farm scale requires construction of a series of water balances to determine flows in each different component of the system. Ideally, data collected from water meters located on the farm may provide water use data, but may provide little information on water consumption. In many cases, water consumptions and flows must be predicted by indirect means, based on livestock production, feed intake, crop production, climate and other data collected during a site assessment.

The general areas of focus for conducting a farm-scale assessment include:

- On-farm feed production and purchased feed (including rain-fed systems, irrigated systems, pastures and grassland systems, and flooded feed systems) as well as water used and consumed in feed processing.
- Livestock drinking water supply systems, including extraction, storage and supply, with associated losses, to the livestock.
- Livestock water balance, incorporating flows of water within the animal (water ingested with feed and drinking, including metabolic water production), respiration and perspiration losses, water incorporation into the product and water excretion in urine and manure.
- Water used and consumed for cleaning, cooling and farm administration.

Data shall also be collected regarding livestock numbers and live weight production, and where drinking water is predicted, an integrated assessment of production, feed intake and water intake is required to ensure consistency.

4.1 Feed production

4.4.1 Water balances of feed production

A water balance should be performed for each unit process contributing to the supply chain. The water balance quantifies all elementary flows - that is, input and output (flows) that cross the system boundary. In accordance with ISO 14046, the elementary flows are listed and the following defined: Quantity of water used, resource type (including precipitation, surface water, sea water, etc.), types of usage (evaporation, transpiration, incorporation, return, consumption, etc.), temporal and geographical aspects. Typically, the results of a water balance will be reported relative to the reference flow appropriate for a particular process - for example, per tonne of grain (in a feed system).

In accordance with ISO 14046 “water consumption” refers to water removed from, but not returned to, the same drainage basin. Water consumption can be due to evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea. Water consumption can refer to both blue and/or green water and should be identified as such when building the inventory. Water inflows and outflows are described in general terms in the next chapter.

Land use occurring in the life cycle of livestock may change hydrological flows of water on surface and in ground. Changes of land use may affect the partitioning of precipitation between surface runoff, percolation and evapotranspiration and therefore water consumption. Specific notes on the issue of land use are available in 5.1.8.

This chapter applies to feed ingredients of plant origin which all require water to meet the growth and transpiration requirements of the plant. Inputs of water to the feed system include rainfall or irrigation depending on the climate and production system. Outputs include percolation to groundwater, surface runoff, evaporation, transpiration and removal of water in biomass (as harvested feed or ingested by grazing animals). Removal of water in biomass may be transferred to a different drainage basin depending on the nature of the feed. Evaporation and transpiration are considered water consumption as these are not returned to the drainage basin. Water in plants eaten by grazing animals and subsequently excreted as urine or in manure in the field is a recirculation within the feed system boundary. Water associated with urine and manure may evaporate from the system in which case this represents an output of the water balance and a consumptive use. Evaporative losses from irrigation supply systems should also be accounted for as water consumption (Emmenegger et al., 2011).

Allocation of grain crop residue grazing by livestock

At times both the grain and forage may be contained in the same plant, as it the case for cereal grains where both the grain and the straw may serve as livestock feed. In this case green and blue water use should be assigned to the feeds as per the principals of allocation as described in section 2.5. If the straw is not used as feed, then all of water use would be assigned to the production of feed grain. Water use associated with the straw would only be assigned to the portion used as feed as a substantial portion is often left as residue on the land, contributing to soil organic matter.

In some instances, there is an unclear boundary between green and blue water. For example, in the case of a floodplain that is seasonally inundated, the flood water would be considered to be blue water, therefore water consumption by grass or crops using the residual soil water would be considered to be blue water consumption. However, that water retained in the vadose (unsaturated) zone could not be directed to alternative uses (as is the case with green water). This shall be dealt with at the water scarcity impact assessment stage. Both green and blue water consumption are generally not measured in feed production, because evapotranspiration (ET) typically cannot be measured, especially for large areas and hence most commonly, green and blue water consumption are estimated, e.g. by measuring the other components of the water balance with ET as the closing entry, or by modelling. One example for a data source especially for Africa and Near East is the FAO tool WaPor (http://www.fao.org/in-action/remote-sensing-for-water-productivity/database/database-content/en/). In the stables, blue water use can be measured with water meters located on the farm but may as well provide little information on water consumption.

Freshwater consumption of feed production for livestock is heavily influenced by the presence of irrigation in feed production systems, and may vary significantly between farms, local regions and international regions in response to differences in the availability of irrigation water. Consequently, particular attention must be paid to accurately determining the feed inventory even for feed types that make up a small part of the ration. For example, a 6% inclusion rate of cottonseed from irrigated cotton production fed in the ration of beef cattle was found to contribute 25-36% of blue water consumption for the finishing stage in eastern Australia (Wiedemann et al., 2016).

Where feed is produced on-farm, as is common in ruminant systems, collecting irrigation water use inventory data is an important aspect of the foreground system. In this case the efficiency of different techniques for irrigation schemes can then be taken into account. If no primary data is available care must be taken to ensure that the proportion of farms using irrigation, and the amount of water used, is representative of the region or national system being investigated. Small differences in irrigation can have very large impacts on freshwater consumption for livestock. In regions where water availability is variable, it is also important to consider if the season when water use inventory data are being collected is representative. Seasonal variability was found to change freshwater consumption by almost two-fold between a low water availability and high water availability year (Wiedemann et al., 2017b). The water use inventory shall be crop specific, including geographic location of the watersheds when available, or country of origin. Averages made over diverse geographies (specifically) from the perspective of water scarcity should be avoided as different impact assessment values would result. Hence if two different regions are exporting the same feed component, then both these regions (and ideally the split of import between them) should be specified and not averaged.

The data relative to feed system water balances can be obtained from databases or estimated through modelling (Table 6). Where feed is grown off-farm, care must be taken to ensure accurate and representative datasets are used to determine water consumption. These datasets may require specific regard to ensure water flows are accurate and complete.

4.4.2 Calculation of crop water consumption

The crop water consumption (Q_{ET}, mm) for the determination of the green water inventory and parts of the blue water inventory can be calculated as the cumulative evapotranspiration during the period of crop growth.

In the absence of estimates from field measurements or remote sensing, Q_{ET} from feed crop or pasture should be calculated using local meteorological information and crop coefficients following FAO guidelines (Allen et al., 1998), Q_{ET} is estimated from the cumulative evapotranspiration under standard conditions (i.e., no plant stress due to water or nutrient constraints) (ET_c), adjusted for soil water availability using the water stress coefficient (K_s).

$$Q_{ET} = \Sigma\ (ET_c * K_s) = \Sigma\ (ET_o * K_c * K_s)$$

ET_o refers to reference crop evapotranspiration (i.e., potential evapotranspiration of short grass). ET_o can be estimated on a monthly or daily step using the climate data from the closest available meteorological stations and empirical formulas (e.g., Hargreaves, Thornthwaite, Priestley-Taylor), and the physically based formula of Penman-Monteith.

K_c is the crop coefficient under optimal agronomic conditions and changes during plant growth depending on plant cover and ground area under wet conditions. It is highly recommended to use local K_c when available. K_c can be calculated locally measuring at field level both ET_c and ET_o ($K_c = ET_c/ET_o$) at different crop stages. When local values are not available, K_c can be obtained from other regional and national studies or using those provided by Allen et al. (1998). To be able to distinguish the productive and non-productive water consumption, the transpiration T_c (mm/day) and soil evaporation E_c (mm/day) can be calculated separately using the basal crop coefficient (K_{cb}), applying a double crop coefficient method (Allen et al., 1998).

The actual crop water consumption will depend on whether there is enough water from rainfall or irrigation to meet the evaporative demand. To calculate Q_{ET} a daily or decadal soil water balance that includes ET_c and changing water storage can be applied. Several databases and agro-hydrological models are available to support the inventory of crop water use. The selection of models/database depends on the objective of the study and resources available (for a review see Payen et al., 2017). Commonly used models are listed in Appendix 2). If modelling is used, the parameters of the model shall be made available in the study report, for transparency. In addition to crop water consumption, there may also be evaporation from artificial storage reservoirs and irrigation canals, which needs to be added.

In cases where the crop is irrigated, Q_{ET} must be partition between blue ($Q_{blue,ET}$) and green water ($Q_{green,ET}$). This can be done in one of two ways.

- Blue water consumption ($Q_{blue,ET}$) may be estimated from measured irrigation applications. Then

  $Q_{green,ET} = Q_{ET} - Q_{blue,ET}$

  However, not all the applied water will be consumed by the crop, and some is returned via drainage and runoff and this is rarely measured. Therefore the consumed fraction must be estimated from local studies or literature and this is a very crude approach and subject to large errors.

- If Q_{ET} has been estimated from a soil water balance model, the model can be run with irrigation to estimate Q_{ET}, and again without irrigation to estimate $Q_{green,ET}$. Then

  $Q_{blue,ET} .= Q_{ET} - Q_{green,ET}$

  This approach is generally considered more reliable as it is not based on assumptions about irrigation efficiency.

The subsequent sub-chapters will give more details regarding the green and blue water inventory for feed crops and pasture and grasslands.

Pastures and grassland

In the specific instance of grazed pasture, the water use inventory of field-grown feed systems shall be expressed using a water balance of all inflows and outflows, distinguishing all irrigation water applied and evapotranspiration of the entire pasture, as well as for the feed eaten only (used in impact and productivity assessments). It is however assumed that all feed produced using irrigation will be eaten (i.e. no field is irrigated for nothing) and hence all effective irrigation water is included in the assessment, whereas only a fraction of the land's received green water is used for the assessment.

The residual biomass that remains after grazing can preserve residual soil moisture and increase the seasonal water reservoir. Much of the plant biomass is in fact underground in the form of root systems that are significant carbon stores and prevent soil erosion. Surface biomass can serve as feed for wild ungulates and provide cover for nesting birds, thereby enhancing biodiversity.

Rain-fed pasture and grassland

Water use inventory (Q_{feed}) in rain-fed pasture and grassland consist of green water inventory $Q_{green.feed}$. To estimate rain-fed pasture intake [t] relevant for productivity assessment only the mass of feed eaten by the livestock should be estimated. LEAP (2016d) provides guideline how to estimate the amount of feed consumed by animals. Two methods are presented here:

1. For an estimate of the intake per animal per day, part of the grazed field needs to be fenced off. After the grass is harvested, it is divided by the number of animals grazing and the number of days the area was fenced off (site-specific, short-term estimates).
2. Use an energy model to calculate the energy demand of the grazing animals (e.g. http://www.fao.org/wairdocs/ilri/x5469e/x5469e0a.htm#part%20a:%20concepts). Subtract the energy fed as hay, silage or cereal concentrates (this requires a measurement of the feed consumed and its energy content). The energy deficit is assumed to be satisfied by grazed pasture. Divide this number by an estimate of the energy concentration in grazed pasture to obtain the dry matter intake of the grazing animals (theoretical calculation).

Based on these rations [t] and yield [t/ha] reported from the farmer or using statistical data on feed input of the animals, total ET (green water consumption, $Q_{green,ET}$) or just T (productive part of green water consumption, $Q_{green,T}$) from precipitation can be estimated as the cumulated ET or the cumulated T from precipitation of pasture and grassland of a farm following the procedure of the water use inventory (Q_{feed}) calculation for rain-fed feed crop production.

Irrigated pastures

Water use inventory (Q_{feed}) of irrigated pastures consists of separated green water inventory $Q_{green.feed}$ and blue water inventory $Q_{blue,feed}$. It includes and distinguishes the mass of feed produced as well as eaten by the livestock, this later being the one used for the assessment. It takes into account rations [t] and yield [t/ha] reported from the farmer or statistical data on yields of irrigated feed and requirement of irrigated feed of the animals. All irrigation water applied for growing pasture or forage is assigned to the portion of the feed that is consumed directly and/or harvested and removed from the field. The approach for obtaining $Q_{blue,feed}$ is the same as explained previously for irrigated feed crop production.

Flood or deepwater feed crop

Water inventory in flood or deep water feed crop (e.g., rice) consists of green water consumption and blue water consumption. E.g. in paddy rice fields evaporation from open water body is much higher than transpiration through the plants. The water consumption in paddy fields can be calculated as the total plant transpiration and evaporation from precipitation and irrigation (green and blue water consumption). Evapotranspiration refers to a real loss to the catchment, while the percolation is not a loss to the catchment (Chapagain and Hoekstra, 2010).

Additional details on calculation of green and blue consumptive water uses of grass, crops and trees are described in section 3.3 of the Water Footprint Assessment Manual (Hoekstra et al., 2011).

4.4.3 Indirect water in feed production

Inputs to the cultivation of feed ingredients

Where available, crop production data should be obtained from local or regional data sources with consideration for fluctuations in yearly averages. If such data are not available, then national estimates may be used. If national estimates are used, the impact of these data on the uncertainty of the model shall be determined and discussed in the study.

Data include the amount of green and blue water consumed in the crop growth process, described in detail in Chapter 4 which may be considered as a background process when feed is not grown on-farm. Water can be associated with inputs necessary to grow crops, such as electricity, fertilizers, pesticides, fuel, etc. and all the water flows associated with crop inputs shall be accounted for. Background data exist but are highly uncertain (Pfister et al., 2011). If those flows represent a significant proportion of the total water consumption, they should be further investigated.

Processing of feed ingredients

Many feed ingredients undergo processing prior to consumption, either as a co-product of another process or as the main product. At the processing plant, water can be required as cooling agent, or as input for the process (e.g. steam in a feed mill). When the process is not under the control of the undertaker of the study, secondary data could be used.

4.2 Animal production

4.5.1 Diet composition and feed intake

Often, more than 90% of the water consumption in livestock and poultry production is associated with the production of feed (Legesse et al., 2017; Mekonnen and Hoekstra et al., 2012). Specific care is required to determine the relative proportions of different feed types consumed, and the geographical location and characteristics of the production systems in which these feeds were grown.

Diet composition differs substantially both across livestock species as well as within different systems and different stages of the production cycle of the same livestock species. Diets that are fed in confinement are often complex, consisting of several ingredients designed to meet the nutrient requirements that are needed to optimize the efficiency of meat, milk or egg production. These ingredients may be sourced locally or imported over vast geographical distances. Other diets may be less complex, consisting of a single ingredient such as the use of grass hay to maintain beef cattle. In some instances, the exact composition of the diet may be difficult to determine, as is the case for grazing cattle or free-range poultry. Where possible, primary data should be used to define diet composition and the geographical site of feed production. When not available, regional or country averages may be used.

The amount of feed consumed by livestock and poultry can be estimated through a variety of means. In a limited number of situations, it will be possible to use measured data to define the amount of feed intake on-farm to produce animal products. This is only likely to apply to situations where livestock and poultry are housed in confinement where known amounts of feed are delivered daily. However, in other cases, livestock and poultry may obtain feed partly or totally under free-range conditions where it may not be possible to have an accurate measurement of the total amount of feed consumed.

In such cases, the total feed intake is calculated from the total energy requirements of the animals as outlined in the LEAP feed, poultry, pig, small ruminant and large ruminant supply chain guidelines.

In practice, there is wastage of feed at the various stages between harvest and feeding and this shall also be accounted for. For example, if there is 10% wastage between harvesting maize and consumption by animals, the water use estimates from crop sources should be based on the amount of feed harvested and not the final amount eaten. At the farm, a significant component of the feed wastage occurs during feeding and this loss should also be accounted for (LEAP, 2016d).

4.5.2 Estimating livestock populations

To assess livestock water use, its productivity and related impacts, it is necessary to define the population associated with the production of the products of interest (e.g. milk, meat, hide, eggs, etc.). A simplified population example for a dairy farm is provided in the appendix (Figure A. 1).

Following LEAP (2016a; b) estimating livestock populations requires accounting for the number of breeding females and males within the animal population as well as those that are used as replacements. The number of animals that are removed from the population for use as meat or as a result of natural mortalities shall also be estimated. The animal population shall be subdivided into cohorts based on age, sex, stage of production and if possible production system. Classes should be developed with an appreciation for the various factors that can influence water use such as season, ambient temperature and feed types used to meet the nutrient requirements of the defined classes. It is recommended that an animal population “model” be constructed from the number of adult breeding animals, a population replacement rate, fertility following LEAP (2016a; b).

In general, annual average population is the most adequate for most livestock, however estimation of yearly populations of some species, such as broilers can prove challenging as several production cycles may occur over a year. In these instances, regional information on the production system shall be used where possible.

The population data may need to be extended to include livestock that are transferred among farms. Furthermore, these production locations may differ dramatically in the extent of their water use, availability and impact. In these instances, it is desirable to have location specific data for each stage in the production cycle, although such traceable information can be difficult to obtain. For national or regional level analyses, this can be accounted for using average data. However, for specific case studies, primary data from all source farms would be required, and where these data are unavailable, it will be necessary to use regional data for the specific contributing farm(s) being considered based on the system boundary of the study being completed.

Calculation of animal productivity also requires average data on male and female adult live-weight, live-weight of animal classes at slaughter and milk production for dairy cattle and goats. Such information is particularly critical when the functional unit is established as a unit of a given product (e.g., L milk, kg meat) and the water consumption needs to be calculated for those functional units. The data relative to animal system water balances can be obtained from databases or estimated through modelling (Table 6).

The water flows at farm level are depicted in Figure 2 for a dairy farm. This type of balance can help selecting the flows staying inside the system balance (e.g. soil water storage) and those which enter and exit the boundary of the system and must be taken into account.

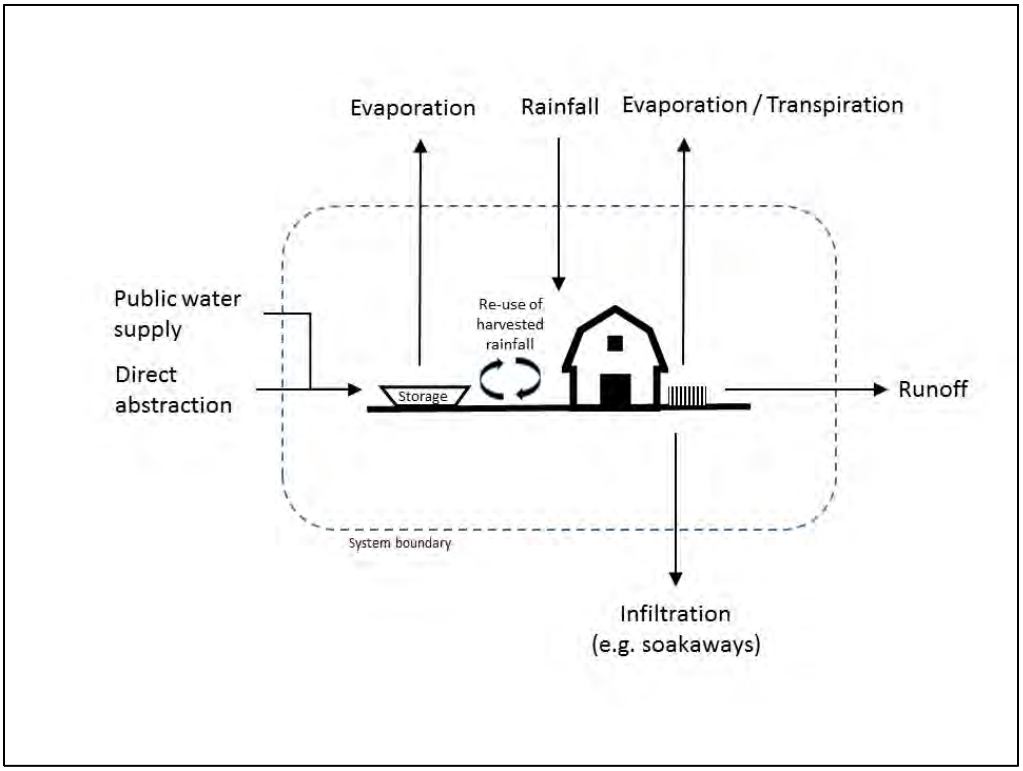

Figure 2: Physical flows of water at a dairy farm level

4.5.3 Drinking and cleaning water

Within the animal, the inflows include ingested water consisting of drinking water and water ingested in feed. The outflows include perspiration, respiration, excretion with manure, excretion as urine, as well as water incorporated into livestock products (e.g., meat, milk, wool, hair) that can be transported off farm (Figure 3). Ingested water will be mainly from blue water sources, whereas water ingested in feed and metabolic water (which arises from feed also) may be from green and/or blue water sources depending on the nature of the feed production practices used. In this case, blue and green water outputs can be assessed based on the proportion of blue and green water used for feed production.

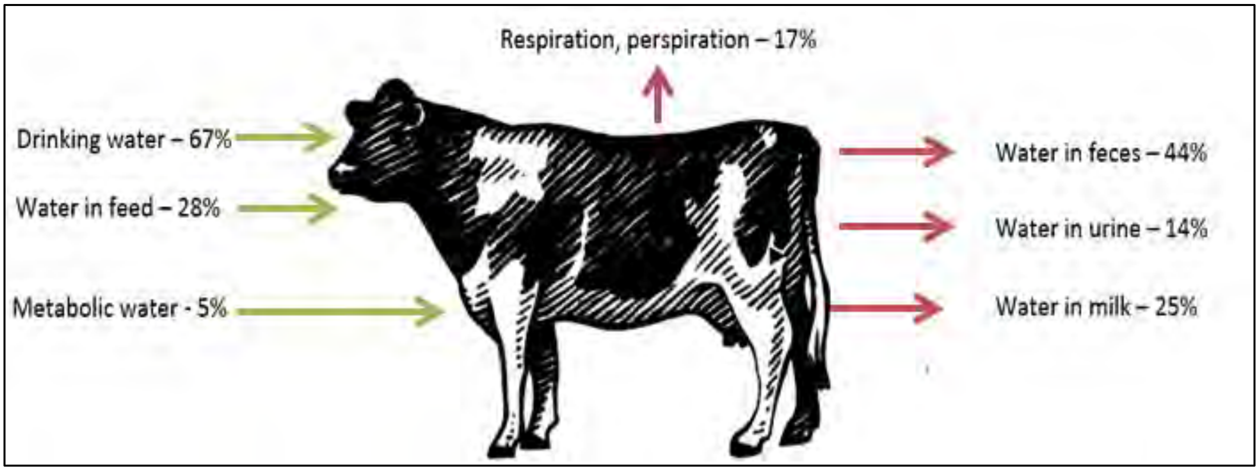

Figure 3: Water balance at a lactating Holstein dairy cow level in [%] (Khelil-Arfa et al., 2012). Numbers should not be used as a default reference as water flows depend on specific milk yields, dry matter intakes, body weights, and diet dry matter contents.

Livestock production systems differ in the amount of water used per animal and in how these requirements are met. There is no single water requirement for a species or an individual. The amount of water ingested depends on a number of factors, such as body weight, physiological state (stage of pregnancy, lactation, etc.), diet, temperature, frequency of water provision, type of housing and environmental stress.

Flows within the animal can be modelled in order to accurately partition inflows and outflows using an animal water balance model (see Figure in section 4, as well as section 11.3.2, LEAP guidelines on Environmental performance of pig supply chains). The state of knowledge of the determinants of water intake varies greatly from species to species but, in all cases, the predictions developed should be used as an approximate guide to the amount of water ingested, not an absolute predictor (Schlink et al., 2010).

Examples of typical ranges in drinking water by livestock and poultry are provided in the Appendix 4.

Poultry

Water requirements in poultry are strongly related to feed consumption and to the air temperature. Once air temperatures exceed 30°C the expected drinking water intake can increase by 50% above normal rates (OMAFRA 2015) Table A. (Appendix 4). Increasing protein and salt concentration in the diet increases the drinking water intake by poultry. There is a clear relationship to protein content as such but also to the protein quality (balance of amino acids) and uptake of electrolytes as well as the resulting drinking water intake.

Swine

Maturity and weight associated with diet, temperature, housing and feeding methods influence largely the swine water requirements. Increasing protein and salt concentration in the diet also increases the drinking water intake by swine (NDSU, 2015) Table A. 10, (Appendix 4).

Small ruminants

Grazing sheep, particularly in the cooler seasons of the year, can require relatively little additional water beyond what they receive through forage. Hot, drier weather, however, will result in increased drinking water intake (OMAFRA, 2015) see Table A. (Appendix 4).

Large ruminants

Cattle

For drinking water demand for beef production, refer to Table A. (Appendix 4).

Dairy herds

Water constitutes 87% of milk, which can be considered as a standard (USDA 2016), and approximately 30% of water ingested by dairy cattle is incorporated in milk (NDSU 2015). Thus, dairy cattle water requirements are strongly influenced by the stage of production and level of milk production (NDSU 2015). An adequate supply of quality water for dairy cattle is extremely important. The water requirements of lactating cows are closely related to milk production, moisture content in the feed and environmental factors such as air temperature and humidity. The cow's peak water intake generally occurs during the hours of greatest feed intake (OMAFRA, 2015) 10 (Appendix 4).

4.5.4 Housing water balances

Water use for servicing includes cleaning animal housing and yards, washing animals, cleaning the milking parlour, cooling and other services to maintain their environment, all of which will vary depending on species and housing type. Intensive production has additional service water requirements for cooling and cleaning facilities, generally resulting in much higher overall water consumption than extensive systems. Intensive production has additional service water requirements for cooling and cleaning facilities, generally resulting in much higher overall water consumption than extensive systems. However, this is in general more than compensated by the more efficient water use so that per kg product intensive systems are more efficient. At times, washing and leakages can be significant, for example water for farm washing is estimated to account for 20% of the blue water used (although mostly not consumed) for dairy cows (Thompson et al., 2007) while leakages represent almost 5%.

The inputs of water to the animal housing system include water from the public water supply, water withdrawn from farm dams and boreholes and locally harvested rainwater. The outputs include small evaporation losses and water discharged to the wastewater management system. Evaporation is a consumptive loss. Water supplies that originate from constructed reservoirs may also have an associated consumptive loss from evaporation.

In many cases farm water use is not metered and even where it is, it is generally not possible to isolate water used for livestock housing from general farm water use, and even less so the consumptive part. Algorithms for the calculation of water flows in animal production can be used (e.g. NAS, 2016; Holter and Urban, 1992; Meyer et al., 2004; Cardot et al., 2008; Krauß et al., 2016).

4.5.5 Wastewater management system balances

Water associated with manure and urine also represents flows, and the final use of this water will depend on the manure management system. In simple systems, where water returns directly to soil as excreta or as a flow to the feed system (as in pasture in a ruminant system) the portion derived from drinking water may be treated as a small addition to the water balance of that system.

Losses associated with evaporation should be noted to ensure flows are not over-estimated. Where manure remains in a managed manure system, the inputs to the wastewater management system is the output from the animal housing system and the flows will be influenced by whether the manure system is a liquid or solid phase system. The outputs include discharge to sewers or watercourses, evaporation during manure treatment and storage and wastewater applied to land (which may be considered a flow to the feed system analogous to irrigation). Only evaporation is a consumptive loss.

Depending on the local water treatment, the quality of the water may have been considerably changed with the potential to have significant impacts on receiving water bodies. Pollutants from improperly disposed animal waste may also be washed into storm sewers by rain water. Storm sewers usually drain directly into water bodies (lakes & streams), carrying many pollutants along with the water. Potential impacts associated with these pollutants should be assessed following water quality impact categories including eutrophication and acidification (LEAP, submitted) as well as (eco)toxicity.

4.5.6 Indirect water consumption in animal production

To capture the indirect water consumption of livestock products, the different life cycle stages taking place before the livestock farm shall be included in the system boundaries. This chapter provides guidance regarding the water elementary flows which shall or should be included in the water use inventory for the following stages, as listed in the LEAP Feed Guidelines version 1(LEAP, 2016d).

4.3 Animal product processing

Processing of livestock products typically use a small but none the less significant proportion of blue water, as such it shall be included in water use inventory estimates. Water consumption (as a consequence of water use) can vary substantially among processing systems with simple systems using water largely for cleaning and washing of produced products. More sophisticated processors use water in washing, chilling, scalding, cleaning and in some instances pasteurization. Even within larger processors water use can vary substantially due to the presence of water treatment facilities and the ability to re-circulate water for use multiple times. Typically, water use (and consumption) by the primary processor accounts for a small percentage of total water use of major livestock products (e.g. Wiedemann et al. 2017a, Wiedemann et al. 2017b) and as a result, the system boundary is often at the farm gate. Where boundaries go beyond the farm gate, information on water use at the processor should be obtained. If such primary information is not available, then default values can be used. A range of water use estimates for the processing of various meat sources is provided in the appendix (Table A. 1, Appendix 4).

4.6.1 Transport

Transport, capital goods and energy carriers

Transport in between the different life cycle stages (in addition to transport of feed and other inputs) may involve direct water consumption. In many countries, trucks may be cleaned before and after transport of animals or animal products for sanitary reason. Water consumption can also be associated with the production of the transport means, like for the other capital goods involved in the life cycle.

Unless it can be demonstrated that the impact of capital goods is not significant, the water consumption associated with capital goods shall be part of the water use inventory. The same applies for energy carriers (electricity, fuel). The recommendations of the LEAP Feed Guidelines shall be used to identify the water use inventory requirements for energy carriers.

Table 6: Main inventory items, data, type of data recommend using, and examples for sources of data to compute water balances.

Main inventory item	Data	Type of data recommend using	Examples for sources of data
Feed system water balances	• Transpiration or evapotranspiration of each feed component • Irrigation water demand • Feed demand resp. feed conversion of livestock for each feed component	1. Field measurement transpiration or evapotranspiration of each feed component with fallow period. Irrigation data from farmers/managers (primary data). 2. Modelled transpiration or evapotranspiration of each feed component with antecedent fallow period. Required information: Land used for the feed production (year of cultivation, origin region), plots (soil types), data on outputs (output of the fields, harvest date, harvest date of the precrop, output	1. Actual evapotranspiration can be determined for lysimeters as the difference between the amounts of precipitation + irrigation and drainage water (e.g. Katerji and Mastrorilli, 2009). 2. Cropwat, Decision support tool (Land and Water Development Division, FAO). http://www.fao.org/land-water/databases-and-software/cropwat/en/; WaPOR (2017) http://www.fao.org/in-action/remote-sensing-for-water-productivity/wapor/en/#/home

		water content, and output name) and plants (variety name, acreage, and average yield) (secondary data) 3. Transpiration or evapotranspiration of each feed component with fallow period from peer-reviewed papers or technical reports (secondary data)	3. E.g.: Drastig et al., 2016; Ercin et al., 2012; Flach et al., 2016; Lathuilliere et al., 2014
Animal system water balances	Drinking water demand	1. Stable measurement on drinking water demand (primary data) 2. Modelled drinking water demand. Required information: head of animals, live weight of the animals, dry matter content of the feed, mean daily ambient temperature, sodium intake and electrolytes intake, lysine intake (methionine + cysteine, threonine) (dairy: milk yield) (secondary data) 3. Drinking water demand from peer-reviewed papers or technical reports (secondary data)	1. Water intake of animals can be continuously monitored (e.g. Cardot et al., 2008; Holter and Urban, 1992; Krauß et al., 2016; Meyer et al., 2004) 2. e.g.: Palhares and Pezzopane 2015, Drastig et al., 2016)
Animal housing water balances	Cooling water demand Service water demand • for surface cleaning • (dairy: For cleaning of milk tank • for cleaning of milking equipment • for udder cleaning)	1. Stable measurement on cooling water demand and service water demand (primary data) 2. - Modelled cooling water demand. Required information: Mean daily ambient temperature (secondary data) - Modelled service water demand: Surface areas, number of rinsing cycles, number of cleaning	1. Water demand for cooling and service can be continuously monitored (e.g. Krauß et al., 2016) 2. e.g.: Drastig et al., 2016,

	procedures (dairy: Number of milking processes) (secondary data) 3. Water demand on animal housing from peer-reviewed papers or technical reports (secondary data)	

5. Assessment

5.1 Water scarcity impact assessment

5.1.1 Introduction

General

Water scarcity impact assessment is the phase to assess the potential environmental impacts associated with the amount of water consumption quantified in the water use inventory phase (ISO 2006a; ISO 2006b). The same amount of water consumption occurring in different places does not correspond to the same environmental impacts because water availability and vulnerability of environment are not homogeneous in the world. Impact assessment provides additional information to interpret the different potential contributions to environmental impacts for the target livestock along the life cycle.

There are several impact pathways leading to potential environmental impacts associated with water use, whether the impacts will affect human health, ecosystem quality, or more generally, local scarcity. The selection of impact categories, category indicators and characterization models shall be consistent with the goal and scope of the water use assessment.

Inventory results are converted to numerical values of category indicators in the characterization step. The calculation is performed by the multiplication of inventory results with characterization factors (i.e. acting as conversion factors from water inventories to impact category indicators).

The steps above are the required parts of water scarcity impact assessment. Subsequent weighting and aggregation of different category indicators, if several are used, is an optional element, and shall be done following ISO 14046:2014.

5.1.2 Selection of impact categories

The selection of relevant impact categories is one of the most important key elements to obtain the appropriate results corresponding to the goal and scope of the assessment. In general, the environmental issues related to water use are classified into two aspects: Quantity and quality. However, in this document only quantity aspects are discussed. Other guidelines can be referred to for water quality assessment following ISO 14046:2014, covering eutrophication, acidification and (eco)toxicity (such as : Guidelines for environmental quantification of nutrient flows and impact assessment in livestock supply chains (LEAP, 2017)), PEF Recommendations (Technical Secretariat for the Red Meat Pilot, 2015; Technical Secretariat, 2015a, 2015b, 2016), UNEP/SETAC Life Cycle Initiative (Sonnemann and Valdivia, 2007), etc.

Regarding quantity aspects, sufficiency of water resources to meet the local demand is of concern in the context of environmental impacts by water use. “The extent to which the demand for water compares to the replenishment of the area” is defined as water scarcity in the water footprint ISO standard (ISO 14046:2014).

The Water Footprint Manual (Hoekstra et al., 2011) also discusses broader dimensions (environmental, social and economic impacts) of sustainability in water use. While the scopes of impact categories defined in the ISO standard of water footprint (ISO 14046:2014) and the environmental dimension of the Water footprint Sustainability Assessment (Hoekstra et al., 2011) are similar, the latter focuses more on the quantification of water volumes used in areas and periods designated as "unsustainable" (i.e. where human consumption and environmental flow requirements already exceeds renewable availability) rather than quantitative potential impacts on the environment, as targeted in the former.

However, both of these relate to water scarcity, as described below.

Water scarcity

Water consumption throughout the life cycle of livestock may lead to a reduced availability of water in an area and may create damage on the environment. The severity of deficit in water resource depends on the extent of demand for water compared to the replenishment in an area. In the calculation of the impact category *water scarcity* (ISO 14046:2014), a scarcity index is used and results in a category indicator generally representing the potential impacts, via deprivation of water resources to users in an area. In most cases the index is continuous, allowing for a range of level of scarcity being described (as in 5.1.4 A), whereas in some cases it is used in a binary approach, equivalent to using a value of 1 when demand is larger than availability, and 0 where it is not the case (as in 5.1.4 B).

5.1.3 Selection of category indicators and impact assessment models

Category indicators are quantifiable representations of impact categories. In general, category indicators represent natural phenomena occurring on the way to the endpoint damage like human health and ecosystem quality. Category indicators may be chosen anywhere along an environmental mechanism, described by the impact pathway from human intervention (here water consumption) all the way to damages on the environment (ISO 14044:2014). A water scarcity category indicator assesses the contribution of the product, process or organization to potential environmental impacts related to pressure on water scarcity. Each method presents specificities and should be well understood when applied. Details on the two recommended methods, and their intended goals are provided below, as well as a non-exhaustive list of other methods available in Appendix 6 (Table A. 2). At this point, contribution to water scarcity is assessed via the consumption of blue water only (see discussion on green water in 5.1.8).

Many different water consumption impact assessment models have been developed as described in Appendix 5. While some of them are conceptually similar, there are differences in the details of modeling (model structures, data source of parameters, definitions of scarcity and environmental water requirement, spatial coverage and resolution, temporal resolution, etc.). The choice of impact assessment model influences the results of impact assessment. As already tested in a method comparison study (Boulay et al., 2015b), some differences in models characterizing the same impact pathways were found although most characterization factors were similar and consistent in rank. A case study of sensitivity analysis of model choices proved that the impact assessment results are different depending on the choice of models (Boulay et al., 2015c). Therefore, the choice of an appropriate impact assessment model is a crucial issue in the impact assessment phase.

Several scarcity indexes and approaches exist to assess potential impacts associated with scarcity. Two of them are recommended here (AWARE and BWSI, described below), but the reader is invited to consult the literature and most up to date reviews which describe and analyze other available methods (such as Sala et al, 2017). In addition, the ISO document TR 14073 (ISO/TR, 2017) contains a series of application examples of ISO 14046, with several methods used and illustrated. LEAP Water TAG recommends applying at minimum the two recommended water scarcity impact assessment methods for best practice and as sensitivity analysis.

5.1.4 Water scarcity impact assessment

Most of the scarcity indicators that exist, both within and outside LCA practices, relate human (blue) water use (withdrawals or consumption) to local and renewable (blue) water availability. Several of them also reserve part of the flow for aquatic ecosystems requirements. The way that these parameters are related to each other, additional modelling aspects, scales, units and data sources result in a variety of scarcity indicators and interpretation. A good understanding of the chosen method(s), units and meaning is necessary when interpreting results from a water scarcity footprint, and results obtained from different methods should not be compared in absolute values.

Recommendation summary

A consensus could not be reached within the group regarding one water scarcity impact assessment method. Therefore, it is recommended to apply at least two methods: AWARE and BWSI.

These two scarcity indexes are recommended for different reasons, including: 1) the detailed resolution at which they are provided (monthly and watershed based), 2) the consideration of environmental water requirements and 3) the level of support from their respective communities.

The AWARE method provides factors between 0.1 and 100 m^3 world-eq/m^3 consumed and the Blue Water Scarcity Index (BWSI) allows identifying regions where BWSI>1. Both methods assess water scarcity at a localized spatial scale, on monthly basis, and accounts for the flows required to remain in the river to sustain flow-dependent ecosystems and livelihoods. This provides an accurate picture of water scarcity making visible the variability of water scarcity along the year, which might be underestimated when measured or averaged at a full basin scale and on an annual level (Mekonnen and Hoekstra, 2016). While both methods use the three parameters 1) human water consumption, 2) water availability and 3) environmental water requirements (EWR), this later term is assessed differently. In AWARE, a monthly and regional fraction between varying between 30-60% of available flow is used (based on Pastor et al, 2014) whereas in BWSI a constant 80% is used everywhere (based on Richter et al, 2011). Details of the two methods are further described below.

A. AWARE method

For the assessment of impact on water scarcity, the AWARE model (Boulay et al., 2018) has been recommended by UNEP/SETAC Life Cycle Initiative based on the consensus building by international stakeholders (UNEP, SETAC, & Life Cycle Initiative, 2017). The AWARE model captures the potential impacts of water consumption in a watershed by representing the amount of remaining water in a watershed after the deduction of human water consumption and environmental water requirements. Thus, the scope of the AWARE method is to assess the potential to deprive another user (human or ecosystems) in a watershed by allowing for a relative comparison and aggregation of water consumption in different regions of the world, based on the water available after considering human and aquatic ecosystem demand. The results of water use impact assessment with the AWARE model identify the quantitative difference of potential impacts of water consumption in a process of livestock production, and allows for comparison with a benchmark.

The characterization factor of AWARE expresses the relative amount of available water remaining per area in a watershed, compared to the world average, allowing the comparison of cubic meters consumed in different regions of the world, converting them to cubic meter world equivalent (m^3 world-eq). This method is used by multiplying the local factor provided by the method (www.wulca-waterlca.org) with the corresponding local water consumption obtained in the water use inventory, to result in m^3 world-eq. The assessment can be performed at the monthly or annual scale.

From Boulay et al. (2018) the factor is calculated as follow (and provided online per watershed and country):

$$AMD_i = \frac{(Availability - HWC - EWR)}{Area} \qquad \text{Eq.1}$$

$$CF_{AWARE} = \frac{AMD_{world\ avg}}{AMD_i}, \qquad \text{for Demand<Availability} \qquad \text{Eq.2}$$

$$CF_{AWARE} = Max = 100, \qquad \text{for } AMD_i < 0.01 * AMD_{world\ avg} \qquad \text{Eq.2a}$$

$$CF_{AWARE} = Min = 0.1 \qquad \text{for } AMD_i > 10 * AMD_{world\ avg} \qquad \text{Eq.2b}$$

"Where demand refers to the sum of human water consumption (HWC) and environmental water requirements (EWR) and availability is the actual runoff (including human impacts on flow regulation and from water use), all calculated in m^3/month and area in m^2. AMD_i is calculated in $m^3/m^2 \cdot$month and the remaining volume of water available for use once demand has been met, per unit area and time ($m^3/m^2 \cdot$month). The value of $AMD_{world\ avg}$ is the consumption-weighted average of AMD_i over the whole world (0.0136 $m^3/m^2 \cdot$month). Units of the CF are dimensionless, expressed in $m^3_{world\ eq.}/m^3_i$ (Eq. 3)." (Boulay et al., 2018).

B. Blue water scarcity index

This index is introduced in Hoekstra et al. (2012) and used to identify water consumption which occurred in an area where water is consumed beyond its availability for human uses. The approach in which this index is originally presented uses the Blue Water Scarcity Index (BWSI) to identify processes with water use in regions where local consumption violates environmental flow requirements (BWSI>1), as well as the fraction of water used occurring in such areas. This method therefore sums the water volumes used in areas with BWSI>1. The use of this index assesses whether or not water use in a process occurs in a region where the amount of water consumption is within the available amount for human activities or not. It is equivalent to the use of a CF of 0 or 1 (when BWSI is below or above 1, respectively) for the calculation of water scarcity category indicator as described above.

Details of this index are available in Hoekstra et al. (2012). Using the same terminology as above, the Blue Water Scarcity Index is described as:

$$BWSI = \frac{HWC}{Availability - EWR}$$

The index is unitless, computed on a monthly scale and is fully described in Hoekstra et al. 2012. This index is used in a binary manner, accounting - and summing - water consumption occurring in regions/months with BWSI>1. The result of the indicator is reported in cubic meter or in a fraction of the total water consumption.

5.1.5 Additional methods and sensitivity analysis

As mentioned above, the choice of impact assessment methods is influential on the results of impact assessment. It is recommended that two methods be applied as to follow best practice and provide useful sensitivity information on the choice of method. In addition to the two recommended methods, other methods are listed in the Appendix 6 and are available in the literature, including other methods used in the past as well as upcoming SDG 6.4.2 indicators (http://www.fao.org/sustainable-development-goals/indicators/642/en/). This may be helpful for comparison with previous studies or results from other initiatives. Consistency of the indicator used across the entire product system (and compared system when applicable) is required.

5.1.6 Assessment of water scarcity impacts

Using data collected as per Chapter 4, potential impacts associated with water consumption can be calculated using water use inventory results and their related scarcity-based factors. Figure 4 depicts a schematic diagram of a hypothetical livestock product system as an example of water use impact assessment. Table 7 shows illustrative water use inventory results and impact assessment factors examples of water scarcity impact assessment using AWARE and Blue Water Scarcity Index (BWSI).

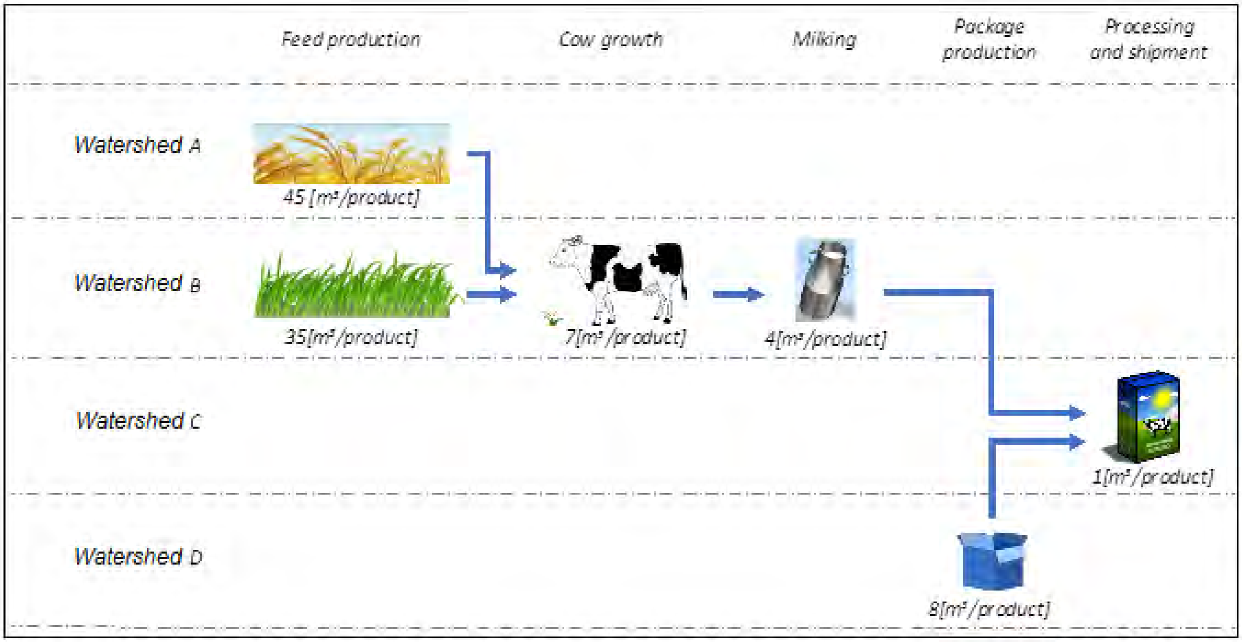

Figure 4: Schematic diagram of a hypothetical livestock product system (e.g. dairy product)

Table 7: Water use inventory results (illustrative) and impact assessment factors examples of water scarcity impact assessment using AWARE and Blue Water Scarcity Index (BWSI) for a hypothetical livestock product system (e.g. dairy product)

	Inventory results	Scarcity factor		Impact Assessment		
	Water consumption [m^3/product]	AWARE model [m^3- world eq./ m^3] (Boulay et al., 2018)	Blue Water scarcity Index (Hoekstra et al., 2012)	Water scarcity footprint (using AWARE) [m^3- world eq.]	Does the overall water consumption in the area exceed the available water for humans?	Fraction of product's water consumption located in regions with BWSI > 1
Feed production	45	10	2.10	450	Yes	45%
	35	0.5	0.15	17.5	No	-
Cow growth	7	0.5	0.15	3.5	No	-
Milking	4	0.5	0.15	2	No	-
Package production	8	1.5	0.80	12	No	-
Processing and shipment	1	3	1.50	3	Yes	1%
Total	**100**	**-**	**-**	**481**	**-**	**46%**

Table 7 summarizes the water inventory results and scarcity indexes, with resulting values for the water scarcity impact assessment of the hypothetical system. Impact assessment of water consumption for each process and each area can be calculated by multiplying the water consumption inventory results and characterization factors (here water scarcity indexes) for the concerned area. The result of the impact assessment with the AWARE model quantifies, for a water consumption in a specific location (i.e. the water inventory), the corresponding volume of water equivalent to that consumption in an average world location, considering the potential to deprive other users. For instance, the potential impact of consuming 45 m^3 in watershed A is equivalent to a consumption of 450 m^3 water consumption in a world average area, based on watershed A having 10 times less remaining water then the world average (and hence a CF equal 10 m^3world-eq./m^3).

When using the Blue water scarcity index as per Hoekstra et al. (2011), if the BWSI factor exceeds one, it means that the overall water consumption in the area violates the environmental flow requirements. In this assessment, water consumption in such areas is identified and the corresponding fraction of the product's water consumption is quantified based on whether BWSI is below 1 or not, corresponding to the multiplication of the inventory flow with a CF of 1 or 0, respectively.

Note: The calculation procedure used with the AWARE method (multiplication of water use inventory with a characterization factor) will generally apply to most of water use impact assessment models presented in the Appendix 5: Blue water scarcity indicators (Table A.2).

5.1.7 Important aspects in impact assessment

The geographical coverage has to be defined according to the scope of the water footprint study and the scale of the environmental impact assessment. Impacts of water consumption are local. It 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. Water use 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 scarcity. Most water monitoring and reporting programs operate at a catchment scale, however modelling of an activity for the purpose of calculating emissions is done at the farm scale.

“Environmental relevance must be taken into consideration if water footprints are to inform decision making and policy development. Water consumption in a region of low scarcity does not have the same potential to deprive humans and ecosystems as water use in a region of higher scarcity (where scarcity refers to the extent to which water availability compares to the demand, ISO 14046:2014).” (Ridoutt et al., 2012).

The main challenge in a water footprinting is to reach a compromise between global and local data:

- Global data is generally more available to cover background processes to the life cycle of livestock products. Meanwhile, spatial resolution of data used for modeling the impacts tends to be lower than that of target processes. Global data may be more readily available; however, relevance of the results may be lower than with local data.
- Assessment methods based on a local data consider local specific conditions, which helps improve relevance and representativeness of the local situation. However, data collection for local scale assessment requires additional effort and time. This challenges the application of high spatial resolution data at a global scale coverage including background and upstream in the supply chain.

To help and meet this challenge, this guide proposes a tiered approach, where Tier 1 is a global approach and Tiers 2/3 more local approaches (see section 3, Table 5 and Appendix 8).

Temporal coverage should account for the temporal variability associated to all processes of water use and water consumption through the life cycle of livestock products. 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 it is preferable to have data from multiple years to account for inter-annual variation.

5.1.8 Working towards impact assessment of green water consumption

Absolute green water flows to the atmosphere

Green water flows should be quantified in the water use inventory. However, to a greater or lesser extent, these flows are part of the natural hydrological cycle. As such, these flows are not considered water consumption attributable to the livestock system for the purposes of water use impact assessment. Hence, impact assessment shall not be performed on absolute green water flows (Rost et al., 2008). Where a livestock production system leads to a change in green water flows compared to an alternative land use or land management system, water use impact assessment may be considered for this difference, as described below, and subject to the precautions described.

Decrease in green water flows to the atmosphere

Where land use change or land management leads to a reduction in E or T from the land, this may result in an increase in drainage and runoff that can potentially increase the local availability of blue water. In such cases, the possibility exists to assess the positive impacts on blue water availability using the same models described in Chapter 5.1.4. However, there are at least three complicating factors: (1) assessment of the impacts from a change in ET requires the selection of a reference land use/land management state. Potential natural vegetation (PNV) is one possibility (Núñ et al., 2013; Ridoutt et al., 2010). However, this reference state does not necessarily make sense in relation to some policy and decision making contexts. (2) In Life Cycle Assessment (LCA) potential impacts should be assessed as completely as possible. If an assessment includes potential benefits from additional blue water made available by land use change but excludes other potentially negative impacts, the results could be considered incomplete and misleading. At the present time there is a paucity of water use impact assessment methods addressing potential impacts on ecosystem services from land use change and those that have been proposed are limited in scope and yet to be widely adopted. (3) Apart from the local impacts on water availability, changes in ET have the potential to impact atmospheric moisture recycling at larger scales, now referred to as precipitation sheds (Keys et al., 2012). A land use or land management change that alters the local ET flow can thereby have local, regional and even continental impacts on precipitation (Ellison et al., 2012; Berger et al., 2014; Launianen et al., 2014; Harding et al., 2013; Keys et al., 2016; Lathuillière et al., 2016, etc). What is important to note are the large uncertainties associated with modelling these processes, as different climate models are likely to deliver different results.

Increase in green water flows or green water interception

Where land use change or land management leads to an increase in evaporation or transpiration or the diversion of green water flows, this may result in a decrease in drainage and runoff that can potentially decrease the local availability of blue water. It is possible to assess water scarcity impacts associated with this change, and the same blue water impact assessment models discussed in Chapter 5.1.6 are recommended.

Soil and water conservation measures

Local soil and water conservation measures can play a critical role in improving the productivity of crop and livestock production systems as well as safeguarding the local and downstream provision of ecosystem services. These measures can include terracing and the creation of furrows which increase water infiltration into the soil and reduce overland flows and soil erosion. They can also include the application of different irrigation technology, employing different irrigation strategies like precision or deficit irrigation, and management of soil cover to avoid soil loss and unproductive green water evaporation e.g. conservation tillage, manuring and mulching (Chukalla et al., 2015). In addition, they can include management of soil health to increase soil organic matter and water holding capacity. Taken together, these measures can improve the local productive use of soil moisture and may also support groundwater recharge for the benefit of downstream communities and ecosystems. They also reduce erosion and thereby the sedimentation impacts experienced by downstream water users and ecosystems (Quinteiro et al., 2015a). Soil and water conservation measures are especially important in arid and semi-arid regions where the incidence of rainfall during the cropping period may be inadequate or marginal and cropping success depends critically on the use of stored soil moisture (Hunink et al., 2012; Scheepers and Jordaan, 2016). However, as important as these measures are, there can be great challenges associated with quantifying the impacts spatially and temporally (Jewitt, 2006; Hunink et al., 2012), other than the direct benefits on crop yield at the site where the soil and water conservation measures are practiced. As such, no recommendations regarding water use impact assessment models can be made at this time to capture this. However, to support improved agricultural practices and the implementation of policies that link water users within a catchment for mutual benefit (such as PES: Payment for Ecosystem Services), further impact assessment research on this topic is strongly suggested.

Some productive and agronomic best practices that can be used to improve water productivity (Doreau et al. 2013):

- Knowing all environmental legislation related to its activity and the management of water resources and soil;
- Using inputs considering all environmental, technical, and productive conditions, and analyzing soil fertility;
- Monitoring the soil agronomic features (pH, nutrient and mineral soils content, and texture), temporal conditions, and soil/crop nutrient status and evaluating if it is optimal to the crop;
- Using soil conservation practices, including winter cover crops, and appropriate tillage practices;
- Having a nutrient management plan;
- Considering agricultural and ecological zonings.

5.2 Assessment of water productivity

Water productivity (WP) is used as a measure relating the livestock product system value (e.g. kg of meat, liter of milk, number of eggs, calories or protein content in the case of food products, or its economic value) to its water consumption (Molden, 1997; Molden et al., 1998; Molden and Sakthivadivel, 1999; Descheemakeret al., 2010; Prochnow et al., 2012). WP may be calculated using the different livestock product system values depending on the scope of the study.

Water productivity (direct and indirect) can be expressed with the following formulae:

$$WP_{mass}[kg/m^3] = \frac{Mass_{output}}{Q} \quad \text{or} \quad WP_{mon}[\$/m^3] = \frac{Revenues_{output}}{Q} \quad \text{or}$$

$$WP_{energy}[\mathrm{GJ}/m^3] = \frac{\text{Food energy}_{output}}{Q}$$

WP_{mass}	water productivity on mass base	[kg_{FM} /m³ Q, kg_{DM}/m³ Q]
FM, DM	fresh matter, dry matter	
WP_{energy}	water productivity on metabolizable food energy base	[MJ/m³ Q]
$WP_{protein}$	water productivity on protein content base	[kg/m³ Q]
WP_{mon}	water productivity on monetary base	[€/m³ Q]
Q	water consumption	[m^3/yr]
$Mass_{output}$	mass output	[kg_{FM}/yr, kg_{DM}/yr]
$Energy_{output}$	food energy output	[GJ/yr]
Revenues	total revenues	[€/yr]

WP is expressed on a mass basis (WP_{mass}) or on a monetary basis (WP_{mon}) per volume of water consumed (Q) for the process or stage assessed. To give an idea about the use of blue and green water the WP shall be reported with fractions of green and blue water consumed: WP (percentage share of blue water/ percentage share of green water) [kg/m³]. An example for the value of the direct and indirect water productivity for a Brazilian broiler production (including purchased feed, animal breeding) on a mass basis is $WP_{indirect + direct,Farm}$ = 0.292 kgCW/m³ (Drastig et al., 2013) (0.3%/99.7%).

Water productivity shall be determined for individual inputs and sub-processes within the system (e.g. feed production and for products leaving the farm gate) and optionally for the overall livestock production system. The metric shall report shares for green and blue water (Table 8). WP shall be calculated and reported by unit process level for which input and output data are quantified (e.g. output as ton of soy and Q as ET or T of feed crop production from unique fields or locations, overall feed production of one feeding ratio component, total feed purchased or on-farm produced). Q may be subsequently aggregated if needed to assess overall performance of a farm or for primary processing (e.g. Farm Output as kg fat and protein corrected milk (FPCM) per year over Q as $Q_{Farm} = Q_{Feed,ET} + Q_{Animal} + Q_{Housing}$).

Depending upon direct and indirect water needed for production, two different water productivity metrics shall be distinguished:

WP_{direct}

Direct water productivity (in output unit per m^3) is calculated for a specific process, unit, or stage, including only the direct water used, as defined in the glossary, but in this case also in the same location (i.e. in case direct water consumption of different foreground facilities would take place in different basins, they would each have their own WP_{direct} calculated). The goal of this metric is to identify improvements in efficiency of direct water use, compared with relevant benchmarks and track the performance of the system.

$WP_{direct + indirect}$

The calculation of water productivity (in output unit per m^3) is performed on more than one unit processes and life cycle stages, and aggregates water use over different units potentially located in different regions. For example, imported feed water use would be included in the farm's water productivity. This can lead to a metric such as X kg LWt/m^3, over the entire supply chain.

In general, the goal and scope of the water use assessment will guide the assessment of water productivity. However, the $WP_{direct+ indirect}$ metric shall always be accompanied by the WP_{direct} for all individual parts of the system as well as the water scarcity footprint as described in Chapter 5.1, in order to prevent misguided decisions which would not represent an environmental improvement (i.e. if a higher productivity is associated with a higher water scarcity footprint for example).

5.2.1 Calculating feed water productivity

Feed crop WP shall be estimated by the ratio of the yield of the field (cropland or pasture) and the evapotranspiration (ET) from the field from harvest of the previous crop till harvest of the crop. ET from cropland and pasture results from the consumption of green water (in rain-fed systems) or a combination of green and blue water (in irrigated systems) (see chapter 4.4.1 “Feed system water balances” and Table 8.

The transpiration part of ET is the productive part of ET contribution to biomass build-up; the evaporation part of ET is the unproductive part of ET (evaporation of water intercepted by the plant canopy and evaporation directly from the soil). The unproductive part of ET can be seen as a ‘loss’ but can be included in the WP calculation, so that all water use is captured in the equation and that improvements in terms of reducing unproductive evaporation is reflected in the water productivity metric.

Ruminant animal production systems often involve animal grazing. Green water consumption of rangelands and cropland shall be distinguished as the water productivity varies. Furthermore, there might be no alternative use of rangeland other than grazing. This issue and the related opportunity cost can be highlighted by distinguishing between green water use from ‘rangelands not suitable for crop production’ versus green water use from ‘croplands’ and ‘rangelands potentially suitable for crop production’.

Table 8: Definition of water productivity metrics of unit processes (expressed as WP) for feed production (e.g. for on-farm production and purchased feed), animal production (including on-farm production and purchased feed, animal breeding) and primary processing on a mass basis.

Stage/Scale	Output	Q	Metric [kg/m³] (blue water/green water)
Feed on-farm production			-
Feed component on field scale e.g. soybean	$Output_{Feed}$: Fresh matter [kg] or Dry matter [kg] of one feeding component produced in one field	$Q_{direct,Feed}$: ET or T [m³]	$WP_{direct,Feed}$ [kg/m³] (x%/x%)
Feed component from all fields e.g. soybean	$Output_{Feed}$: Fresh matter [kg] or Dry matter [kg] of one feeding component produced in the farm	$Q_{direct,Feed}$: ET or T [m³]	$WP_{direct,Feed}$ [kg/m³] (x%/x%)
Feed ration with all components e.g. soybean and corn	$Output_{Feed}$: Fresh matter [kg] or Dry matter [kg] of the ration produced in the farm	$Q_{direct,Feed}$: ET or T [m³]	$WP_{direct,Feed}$ [kg/m³] (x%/x%)
Feed purchased			-
Feed component on field scale e.g. soy produced in one region	$Output_{Feed}$: Fresh matter [kg] or Dry matter [kg] of one feeding component produced in one field in one region	$Q_{indirect,Feed}$: ET or T [m³]	$WP_{indirect, Feed}$ [kg/m³] (x%/x%)
Feed component from all fields e.g. soy produced in one region	$Output_{Feed}$: Fresh matter [kg] or Dry matter [kg] of one feeding component produced in one region	$Q_{indirect,Feed}$: ET or T [m³]	$WP_{indirect, Feed}$ [kg/m³] (x%/x%)

Feed component from all fields e.g. soy produced in different regions	$Output_{Feed}$: Fresh matter [kg] or Dry matter [kg] of one feeding component produced in different regions	$Q_{indirect,Feed}$: ET or T [m³]	$WP_{indirect, Feed}$ [kg/m³] (x%/x%)
Feed ration with all components e.g. soy and corn produced in different regions	$Output_{Feed}$: Fresh matter [kg] or Dry matter [kg]of the ration produced in different regions	$Q_{indirect,Feed}$: ET or T [m³]	$WP_{indirect,Feed}$ [kg/m³] (x%/x%)
Animal production			-
Farm	$Output_{Farm}$: Fresh matter [kg] or Dry matter [kg]	$Q_{direct,Farm}$: $Q_{direct,Feed}$ + $Q_{direct,Animal}$ + $Q_{direct,Housing}$ [m³]	$WP_{direct,Farm}$ [kg/m³] (x%/x%)
Farm	$Output_{Farm}$: Fresh matter [kg] or Dry matter [kg]	$Q_{indirect + direct,Farm}$: $Q_{direct,Feed}$ + $Q_{direct,Animal}$ + $Q_{direct,Housing}$ + $Q_{indirect,Feed}$ [m³]	$WP_{indirect + direct,Farm}$ [kg/m³] (x%/x%)
Primary processing			-
Processing	$Output_{Farm}$- $Output_{Processing}$ Fresh matter [kg] or Dry matter [kg]	$Q_{direct,Proc}$ [m³]	$WP_{direct,Proc}$ [kg/m³] (100%/0%)
Processing	$Output_{Processing}$ Fresh matter [kg] or Dry matter [kg]	$Q_{indirect + direct,Proc}$: $Q_{direct,Proc}$ + $Q_{Indirect}$ [m³]	$WP_{indirect + direct,Proc}$ [kg/m³] (100%/0%)

The calculation of water productivity requires detailed knowledge of water resource use of processes and products in different watersheds. Gathering of this information shall follow recommendations for water use inventory in Chapter 4 of these guidelines. Considering that livestock contributes 17% to the global food balance, in terms of caloric intake per person per day, and 33% of the protein in human diets (Herrero and Thornton, 2013), the sector's WP may also be measured by the caloric or protein value. When considering economic value, one may consider economic value added (e.g. in dollars, see grey box) which may be obtained from the product's contribution to national gross domestic product (GDP), or average global market prices. Another framework for assessing monetary values is e.g. https://unstats.un.org/unsd/envaccounting/seeaw/seeawaterwebversion.pdf

Water productivity based on monetary farm output

The use of USD to estimate water productivity may be chosen in order to have a simple unit for the measurement of the indicator. The United Nations Sustainable Development Goal on Water is in line with this choice proposing a standard and homogeneous unit. However, the use of USD can be questioned as the measure of value of livestock, pointing out that the valuation is subject to fluctuations in exchange rates, and that expressing the value in monetary terms can lead to unintended consequences (e.g. proliferation of high value livestock animals and products at the expense of local community food needs). Other suggestions include the consideration of global average market prices and internationally trade volumes of the livestock product under study.

5.2.2 Calculating water productivity from energy and other inputs

The water productivity of other unit processes of the livestock production system, e.g. for energy and other inputs such as fertilizers, pesticides, herbicides, cleaning agents and disinfectants shall be calculated from local existing data, when possible. Otherwise, water consumption data could be obtained from existing databases such as Ecoinvent (Ecoinvent, 2015), GABI (GABI, 2016), Quantis water database (Quantis 2012) or tools such as the WBCSD Global Water Tool and used to calculate the WP (WBCSD, 2015).

6. Interpretation of results

The overall aim of the interpretation of the results should be to help different types of decision makers understand the performance related to water use of their product system and to aim for more efficient and sustainable ways of livestock production or consumption, both from the water as a resource and from the overall environmental impact perspectives. Interpretation of the relative environmental impacts shows the urgency to act and of the relative water productivity shows the room for improvement. The interpretation has different audiences; the results should be interpreted in light of who is going to use the report and for what purpose. The interpretation of the results should highlight which points in the production chain can be improved such that impacts are minimized, as identified in the Impact Assessment chapter, with respect to water scarcity and efficiency of production related to water use. Interpretation must clarify the level of aggregation used in the result chapter i.e. interpretation of results for different types of water use (green and blue) should be presented separately and put in the context of each other. More comprehensive presentation of how to interpret water use impact assessment is provided in the source literature of the methods described in chapter 5.

6.1 Interpretation of the result related to impact assessment

The water use impact assessment results provide insight on the potential environmental impacts associated with water consumption for livestock production and livestock products in terms of the physical quantity of water available. This is done via two main metrics: 1) A water scarcity footprint which will quantify the potential user deprivation and potential environmental impacts associated, and 2) blue water scarcity which identifies the fraction of the consumption of a product or process exceeding local available water for humans. Both these metrics relate the system's water consumption to the local water scarcity, as an indicator of its potential environmental impacts or overuse. The results of water use impact assessment shall be analyzed from both an aggregated and disaggregated perspective along the life cycle of livestock production and livestock products. Aggregated impact assessment results provide the overall performance of the target related to physical water scarcity, whereas disaggregated results provide the contribution of each stage and process to water scarcity.

The water use inventory analysis should reveal the following:

- Process stages (life cycle stages) in the supply chain and respective volume of water consumption;
- Total water consumption of all processes, providing temporal reference and location within the drainage basin
- The source of water used e.g. surface or ground water, rain water

The water use impact assessment should reveal the following:

- How much will other users be potentially deprived from this water consumption? (e.g. using AWARE)
- How much will it contribute to water scarcity impacts? (e.g. using AWARE)
- Which stage of my system contributes the most to water scarcity and to which extent? (e.g. using AWARE)

- Where and when is the water consumption exceeding the flow allocated to humans due to basin specific attributes? (e.g. using BWSI)
- What is the fraction of the water consumption that taking place in such basins already exceeding the allocated share to humans? (e.g. using BWSI)

Detailed analysis of the system

Detailed results of the impact assessment using water scarcity footprint into each process will help identify the hotspots of the potential environmental impacts of water scarcity within the production system.

Improvement and mitigation potential

If it is the water consumption (i.e. inventory) that leads to a major difference with the benchmark, assessment of water productivity will serve to find solutions for reduction of water consumption in a process (refer 4.2 and 6.1.4). If it is the geographical location (i.e. characterization factors of the area) that is more influential, then an alternative site for the production process might be sought. However, it may not be necessarily feasible to change the location of the concerned process, because socio-economic impacts might be high and therefore shall be considered if such an alternative is suggested. Thus, solutions from the assessment of water productivity would also improve the potential environmental impact of the process in a feasible way. Priority of improvement can be identified using the information provided by the water scarcity footprint.

The components of the blue water consumption of a product/process which contribute the most to impacts, or which is unsustainable, deserve action in order to improve the situation. Based on the share that a certain water consumption has in the potential impacts, one can set priorities with respect to where to start. One can decide to disregard altogether components that contribute to the overall potential impacts below a certain threshold (e.g. one percent). Prioritizing can also be done based on the relative severity of the various hotspots to which the different water consumptions contribute or on the basis of which improvements can most rapidly and easily be achieved.

Aggregated results of the impact assessment using water scarcity footprint (e.g. using AWARE) along the life cycle help to quantitatively understand the improvement of the livestock system with respect to the situation of physical water scarcity. While water use inventory analysis results may indicate that a process increases water use in a region A and another process decreases water use in a region B compared with a benchmark, net potential impacts on physical water scarcity are not known yet. Water scarcity footprint impact assessment characterizes the potential environmental impacts from water scarcity in different areas with the same metrics, which makes it possible to assess the net potential environmental impacts, even if both increase and decrease of water use in some processes are mixed in the life cycle of the target.

If a process is identified to result in a significant potential environmental impact (i.e. a hotspot in the assessment), the cause of the impact needs to be determined by disaggregating the impact into water use inventory (amount of water consumption) and characterization factor of an area (potential impacts of unit volume of water consumption).

The result of the assessment using BWSI to identify water consumption occurring in regions where water consumption is already higher then available water for human use implies that the product/process is using the environmental flow required by the ecosystems. These regions thus represent hotspots which require special consideration.

6.2 Interpretation of the result of the water productivity analysis

6.2.1 General

The water productivity can be calculated for the whole farm, for feed crops, and for livestock. The water productivity for the whole farm varies among different farming systems closely related to differences in farmers' livelihoods strategies of the respective livestock or poultry systems. Haileslassie et al. (2009) reported water productivity values of 0.15–0.69 USD/m³ for mixed farming systems which integrate both crops and livestock which are typical in the Gumera watershed (Ethiopia). Farmers keep cattle (*Bos indicus*), sheep (*Ovis aries*), goat (*Capra hircus*), horse (Equus caballus), and donkey (*Equus asinus*). The authors suggest that feed, age, breed and herd structure account for variability in WP. There can be a as well a strong variation between and within the feed crops. The differences between the feed crops on a mass base can be attributed mainly to differences in the yields and to a lesser extent to the crop-specific coefficients (Prochnow et al., 2012). High-yielding feed crops such as food-feed crops, or grasses are characterized by high water productivities from 0.34 to 4.02 kgFM/m³ Winput, and vice versa water productivity is in a much lower range from 0.15 to 2.16 kgFM/m³ Winput for feed crops with lower biomass production, such as semi-arid rangelands, grains, or rapeseed (Descheemaker et al., 2010; Prochnow et al., 2012). The food energy-based water productivities of the feed crops in addition vary due to the food energy contents: for sugar beet, the high yields of food biomass in combination with the high food energy contents result in energy-based water productivities that are about 6–20 times higher than those of the other crops. The low yields of e.g. rapeseed are counterbalanced by the high food energy contents of rapeseed oil. The food energy-based water productivities of grains are in the lower range. The farmer's decision on which crops to grow and which livestock to keep mainly depends on natural conditions and general economic framework (Prochnow et al., 2012).

Neither from a nutritional nor from an agronomic perspective would it be meaningful to improve the water productivity of a farm by growing feed crops with high water productivities preferably. The focus for improving the water productivity of a farm has to be put on the large differences in water productivity between the fields with the same feed crops. They can be attributed to a strong variation in the yields that are reflected in a varying output of biomass, food energy, and revenues. As all fields received the same amount of precipitation per hectare, this fact illustrates that the farm output and thus water productivity is determined not only by water but also by many other factors such as soil quality and management practices (Prochnow et al., 2012). The key principles for improving water productivity at process, field, farm and basin level, which apply regardless of whether the crop is grown under rain-fed or irrigated conditions, are: (i) increase the marketable yield of the crop for each unit of water transpired by it; (ii) reduce all outflows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop stomatal transpiration; and (iii) increase the effective use of rainfall, stored water, and water of marginal quality (http://www.fao.org/docrep/006/y4525e/y4525e06.htm and Appendix 6).

6.2.2 Analysis of irrigation scheme

When analyzing an irrigation scheme, it is important to use a terminology that can be used unambiguously. In that sense, the International Commission on Irrigation and Drainage (ICID) recommends that the terminology of Perry (2011) should be used in the analysis of water resources management at all scales. Perry (2011) proposed an analytical framework and associated terms to better serve the needs of technical specialists from all water-using sectors, policymakers and planners in achieving more productive use of water. One important aspect regarding irrigation practices is the distinction between the fraction which is consumed (including beneficial and non-beneficial) and the fraction which is not consumed (including recoverable and non-recoverable).

The efficiency of an irrigation scheme can be increased by reducing the non-productive water losses e.g., soil evaporation losses (Hess and Knox, 2013; Perry, 2011). Moreover, an irrigation scheme should also minimize the non-consumptive fraction through percolation while enough water still percolates for the cleaning of salts from soil. To achieve that, changes of irrigation systems (e.g., from furrow to drip irrigation) will help to reduce those water losses, but it is also important to evaluate whether appropriate irrigation doses are applied at the time that crops need them. Periods of water lodging or water stress can negatively affect to the final crop yield, depending on their sensitivity under saturated or water scarce conditions. As a result, in the end a good knowledge of the water requirements during crop growth stages by farmers is essential to avoid mismanagements in agricultural practices. There is also the option for some crops to not meet full water requirements and design deficit irrigation programs to optimize the crop water productivity.

6.2.3 Comparison of water productivity assessment results

When a comparison of WP results between product systems or within the same product system is made, it shall be based on the same WP metrics. The interpretation should clearly show if there is potential to improve the effectiveness of water consumption. The interpretation should relate the water productivity with respect to the results of the share of blue water and green water separately and combined to make decisions on green and blue water allocation in all stages of livestock production system. If the water productivities are below available benchmarks (i.e. the production is not efficient, meaning that it takes more water to produce compared to benchmarks), then the interpretation of the result should highlight what measures could be taken to improve the situation. This can be limited to identify hotspots in the assessment.

Depending on the goal of the assessment the interpretation should also highlight the geospatial and temporal scales used in developing the benchmarks used. Benchmarks comparison should consider the same production conditions: agricultural (climate, soil, genetic and farming practices) and animals (production system, climate, genetic, nutritional management, type of barns, and technologies and practices for servicing water) or otherwise. It should be clearly indicated when data for these parameters is limited. Comparison from different productive contexts will result in interpretation mistakes and thus are not allowed to propose mitigation practices.

6.2.4 Identification of response options

The outcome of interpretation could help decision making on optimal water use, technologies, geographical locations and agricultural and livestock management both from a water productivity and reduction of potential environmental impacts perspective. The interpretation of results should highlight and help detect areas of opportunity where the livestock production should be adapted (increased efficiency) or where mitigation measures could be applied within the production chain. Additionally, the socio-economic context needs to be accounted for. For instance, extensive livestock systems in arid regions already depend on scarce water and these systems are main contributor to the food security and livelihoods of pastoralists, which needs to be included in the analysis.

As the response options depends on complex sets of variables (basin attributes, size and type of the footprint, the production process and available best practices), only a few top level response options have been presented in Appendix 7.

Response formulation starts with prioritizing where to start first. Table 9 shows that priority depends on both relative environmental impact (which shows the urgency to act) and relative water productivity (which shows the room for improvement). After prioritizing locations and processes where water footprints are not sustainable, the next step is to design appropriate action.

Table 9: Water productivity versus levels of scarcity footprint matrix to guide priority setting - from low priority (0) to high priority (+++)

	Low scarcity footprint	Medium scarcity footprint	High scarcity footprint
high water productivity	0	0	+
medium water productivity	0	+	++
low water productivity	+	++	+++

Source: Adapted from Water Footprint Manual (Hoekstra et al., 2011, Table 5.2)

For prioritization and identifying types of response options, one could follow the following systematic approach by asking questions such as (Figure A. 2):

- Is internal action sufficient e.g. improving your own water consumption?
- Do you need to work with external parties within a basin in a collective action?
- If yes, do you work within a specific group or sector [e.g. corn farmers only], or is wider engagement necessary [e.g. all the stakeholders/sectors in the basin]?

The response could consist of various components and their combinations such as:

- Technology (new investment) and improved practices;
- Efficiency (resource consumption reduction);
- Strategy and due diligence (water consumption reduction across operations, supply/value chain);

- Stakeholder engagement (governance, reputation, incentivizing);
- Knowledge sharing and co-investment (single sector or cross sector collaboration);
- Innovation (developing opportunities) etc.

6.3 Uncertainty and sensitivity assessment

As described in Chapter 3, data requires uncertainty information since it is often highly uncertain due to variability and lack of measured data. The same is true for water productivity metrics and scarcity indices for water use impact assessment, as they are based on global, simplified hydrological models featuring high uncertainty themselves (Scherer et al., 2015) and without detailed differentiation of affected water bodies (e.g. ground and surface water). This is generally the case when assessing complex systems. Uncertainty information can be generally classified into input data uncertainty, model uncertainty as well as choice uncertainties, which are usually not reported in LCA studies (Verones et al., 2017). A recent UNEP report on guiding LCA (Frischknecht and Jolliet (eds.), 2017) highlighted the need for quantitative uncertainty data whenever possible, but acknowledged that this is not practicable in most cases.

Input data uncertainty refers mainly to measured or modeled parameters retrieved from other studies and includes for instance climate data, which can vary significantly when modeling on global scale (e.g. Scherer and Pfister, 2016). Model uncertainty increases overall uncertainty, as discussed in (Lassche, 2013 and Scherer and Pfister, 2016), and different models provide differing results. For water consumption, uncertainties are often especially high, as shown by Pfister et al. (2011) with the lower and upper estimates for irrigation water consumption for the global crop production model (deviating by more than a factor of two for the global sums, mainly reflecting the model uncertainty of irrigation intensity). Based on these and other results, water inventory flows have been assigned a high uncertainty value (in the range of +/-40% for the 95% interval) in ecoinvent 3 (2015), an LCA inventory database that includes water flows and balance for ~10’000 industrial and agricultural processes (Pfister et al., 2016).

Especially in a water scarcity footprint, uncertainty of water flows and scarcity models might lead to non-significant differences in case of weak data quality (Pfister and Scherer, 2015). Nevertheless, uncertainty information and contribution to variance analysis can be used to identify data quality issues in order to improve the assessment. However, better data is often not available in the supply chain analysis or it cannot be improved by the practitioner. In the foreground, improved measurements or detailed modeling techniques might help to reduce uncertainties and thus increase the robustness of the study.

For interpretation of the results it is thus highly important to account for uncertainty of the different inputs to the analysis in order to allow discussion of those uncertainties at least qualitatively as well as for testing alternative options in sensitivity analysis. Uncertainty information can further help to determine a meaningful range for sensitivity assessments beyond the use of different methods as suggested for the water use impact assessment.

The sensitivity assessment is needed to determine

- to what extent the method(s) selected for water use impact assessment affect the outcome of the study
- what complementary information can be derived from different methods

- how robust are improvements form alternative options in terms of water productivity and water footprint
- where better data collection would release in more robust results

Correlated uncertainty (such as impacts in the same location) should be deducted before interpreting overall uncertainty and sensitivity, while uncorrelated uncertainty (e.g. impacts of water consumption at different locations) needs to be fully accounted for in an overall water footprint assessment.

7. Reporting

7.1 General principles for reporting

- Credibility and reliability

For reporting to be successful in improving environmental understanding of products and processes, it is important that technical credibility is maintained while adaptability, practicality and cost-effectiveness of the application provided. Reporting conveys information that is relevant and reliable in terms of addressing environmental areas of concern (adapted from ISO 14026:2017).

- Life cycle perspective

Reporting takes into consideration all relevant stages of the life cycle of the product including raw material acquisition, production, use and the end-of-life stage.

- Transparency

Reporting contains sufficient information to enable the intended user to access information on where the data originated and how it was developed.

- Accessibility

Information concerning the procedure, methodology and any criteria used to support reporting is accessible to the intended user.

- Regionality

Reporting takes into consideration the local or regional environmental context relevant to the area where the corresponding environmental impact occurs including the production, use and end of life stages.

7.2 General requirements

Reporting of impacts and water productivity assessment results shall be performed without bias and consistent with the goal and scope of the study.

The type and format of the report shall be appropriate to the scale (geographical and temporal) and objectives of the study and the language should be accurate and understandable by the intended user in order to minimize the risk of misinterpretation. The type and format of the report shall be defined in the scope phase of the study.

The results, conclusions, data, methods, assumptions and limitations shall be transparent and presented in sufficient details to allow the reader to comprehend the complexities and trade-offs inherent in the impact and water productivity assessment.

Reporting of water productivity results should be transparent by making available the information about each elementary flow separately, as well as data sources. Aggregation of water productivity data (e.g. water use data from different location) shall not be reported without the water scarcity footprint (as defined in ISO14046:2014). The environmental assessment and the product system value assessment shall be documented separately in the report.

Reporting of the water use impact assessment shall be performed following ISO 14046:2014.

Any comparative assertion shall not be based on water productivity assessment or water-related impacts alone, as this is not representative of an overall environmental performance. If results are intended for comparative assertion, a comprehensive life cycle assessment (LCA) is required and ISO 14044 requirements apply.

Reporting of impact and water productivity assessment results can be based on a benchmark in order to present and study water-related environmental performance tracking overtime.

The benchmark used as reference shall be transparently reported. Any changes to the benchmark(s) that occurred overtime shall also be reported.

7.3 General guidelines for report content

According to the goal and scope of the study the internal report can include impact and/or water productivity assessment results.

A water use assessment report should contain the following information:

- Goal of the study: Intended applications and targeted audience and users, methodology including consistency with these guidelines;
- Functional unit and reference flows, including overview of species, geographical location and regional relevance of the study;
- System boundary and unit stages (e.g. to farm gate and farm gate to primary processing gate);
- Geographical and temporal dimensions and scale of the study;
- Cut-off criteria;
- Allocation method(s) and justification if different from the recommendations in these guidelines;
- Data collection procedures
- Description of inventory data: Representativeness, averaging periods (if used), and assessment of quality of data;
- Description of assumptions or value choices made for the production and processing systems, with justification;
- Feed intake and application of LEAP Animal Feed Guidelines;
- LCI modelling and calculating LCI results reported separately for different location and different time span when applicable;
- Results and interpretation of the study and conclusions;
- Description of the opportunities for water-related environmental performance improvement;

- Description of the limitations and any trade-offs;
- Description of the benchmark(s) used as reference in the assessment;
- In the case of performance tracking, a clear reference to the baseline year and any eventual changes occurring overtime.

With specific reference to water productivity/efficiency assessment, results and benchmark(s) shall be reported separately for each process where different locations apply to the system under study.

7.4 Third party reporting

A third party report is a report meant to include information to be communicated to third parties (e.g. i.e. interested party other than the commissioner or the practitioner of the study) (ISO 14044, 2006). According to the goal and scope of the study the third party report should include both water use impact assessment and water productivity assessment results. If only one of the two assessments is performed, the limitations of not performing the other one shall be clearly stated in the third party report.

The third party report shall be made available to the intended users.

To guarantee credibility and transparency of the study a critical review according to ISO 14071 (ISO/TS, 2014) should be performed.

Along with internal report requirements, the following additional requirements shall be applied:

- Executive summary typically targeting a non-technical audience (e.g. decision-makers), including key elements of the goal and scope of the system studied and the main results and recommendations while clearly giving assumptions and limitations;
- Identification of the study, including name, date, responsible organization or researchers, objectives of/reasons for the study and intended users;
- Critical review information when applicable;

With specific reference to water use impact assessment results, the third party report shall also include:

- Descriptions of or reference to all value choices used in relation to impact categories, characterization models, characterization factors, normalization, grouping, weighting and, elsewhere in the water use impact assessment, a justification for their use and their influence on the results, conclusions and recommendations;
- Disclaimer to clarify that an impact assessment related to water scarcity alone is insufficient to be used to describe the overall potential environmental impacts of products.

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Appendix 1: Functional units and reference flows

Table A. 1: List of functional units and reference flows

Livestock	Stage	Functional Unit/Reference flow	LEAP guideline
Piglet	Farm gate	Live-weight (kg)	LEAP (2018) (p. 37)
Spent Snow	Farm gate	Live-weight (kg)	LEAP (2018) (p. 37)
Draught power	Farm gate	MJ	LEAP (2016a) (p. 33)
Milk (large and small ruminants)	Farm gate	FPCM (kg), ECM (kg)	LEAP (2016a) (p. 33)
Milk (large and small ruminants)	Processing gate	Fat/protein content (kg), milk product (kg)	LEAP (2016a) (p. 33)
Egg	Farm gate	Fresh shelled weight (kg)	LEAP (2016c) (p.30)
Egg	Processing gate	Liquid or dry (powder) weight (yolk, whole, white) (kg)	LEAP (2016c) (p.30)
Fibre (small ruminants)	Farm gate	Greasy weight (kg)	LEAP (2016b) (p. 28)
Fibre (small ruminants)	Processing gate	Clean weight (kg)	LEAP (2016b) (p. 28)
Meat	Farm gate	Live-weight (kg)	LEAP (2018) (p. 37)
Meat	Processing gate	Meat product, Carcass-weight (kg)	LEAP (2018) (p. 37)

Appendix 2: List of models

Table A. 2: List of models (most of the proposed models need expert users for meaningful application)

Purpose	Name	Source
Crop growth model; Point or site-specific applications	EPIC (Erosion-Productivity Impact Calculator)	Williams et al., 1989
Simulates vertical transport of water, solutes and heat in unsaturated/saturated soils. The program is designed to simulate the transport processes at field scale level and during entire growing seasons.	SWAP (Soil, Water, Atmosphere and Plant)	http://www.swap.alterra.nl/
Simulates the yield response of herbaceous crops to water; Point or site-specific applications	FAO's AQUACROP (Steduto et al., 2008)	http://www.fao.org/nr/water/aquacrop.html
Calculation of crop water requirements and irrigation requirements based on soil, climate and crop data; Point-specific.	FAO's CROPWAT (Smith, 1992)	http://www.fao.org/nr/water/infores_databases_cropwat.html

Appendix 3: Tables on water balances for swine production

Table A. 3: Example Water Balance for Swine production I (Wiedemann et al., 2012; Wiedemann 2017b)

Source	Source Description	Use Description	Volume (L/pig)	Uncertainty (SD or range)
Inputs (source and use)				
Groundwater (stock)	Blue water	Piggery water supply (includes drinking water, losses, cleaning, maintenance)	453	1.10
Surface water Dam	Blue water supply from on-farm storage dam, subject to storage losses	Cooling water supply	0	1.10
Feed (feed moisture and metabolic water)	Green and blue water relative to the contribution the feed system		26	1.43
Pigs (purchased pigs brought to the farm)			1	1.43
Total inputs			481	

Table A. 4: Example Water Balance for Swine production II (Wiedemann et al., 2012; Wiedemann 2017b)

Outputs (source and use)				
Source	**Source Description**	**Use Description**	**Volume (L/pig)**	**Uncertainty (SD or range)**
Groundwater (stock)	Blue water, drinking water lost via the physiological processes of perspiration and respiration	Evaporative use	38	1.43
	Drinking water assimilated into the animal product	Catchment transfer	5	1.43
	Drinking water excreted in manure and urine	Manure treatment system	167	1.43
	Drinking water supply losses	Manure treatment system	13	1.43
	Shed evaporative losses	Evaporative use	57	1.96
	Cleaning water	Manure treatment system	200	1.96
	Cooling	Evaporative use	0	1.96
	Maintenance / administration	Evaporative use	0	1.96
Total outputs			481	
Balance			0	

Table A. 5: Inputs (source and use) (Wiedemann et al., 2012; Wiedemann 2017b)

Source	Source Description	Use Description	Volume (L / weaned pig)	Volume (L / porker pig)	Volume (L / finished pig)
Effluent from piggery	Combined sources - excretion and cleaning	Manure treatment	624.8	666.2	1495.7
Rainfall capture	Direct capture of rainfall falling on pond	Incorporated with manure treatment flows	162.8	165.9	422.4
Total inputs			787.6	832.1	1918.2
Outputs (source and use)					
Evaporation from effluent pond		Evaporative use	304.8	292.5	834.6
Irrigation to effluent disposal area, Evapotranspiration	Agricultural grade water	Evaporative use	482.8	539.6	1083.6
Total outputs			787.6	832.1	1918.2
Balance			0.0	0.0	0.0

Appendix 4: Tables on water demand for drinking and meat processing of different species

Table A. 6: Drinking water demand chicken (modified from OMAFRA 2015)

Chicken Broiler Age (weeks)	Water requirement (l/1000 birds/day)	
	21ºC	32ºC
1 – 4	50 – 206	50 – 415
5 – 8	345 – 470	550 – 770

Table A. 7: Drinking water demand swine (Water requirements (liters per pig per day) for swine (modified from NDSU 2015)

Class	Water Intake (l/pig/day)
Nursery (up to 27.2 kg)	2.6 to 3.8
Grower (27.2 – 45.3 kg)	7.6 to 11.3
Finishing (45.3 – 113.4 kg)	11.3 to 18.9
Nonpregnant gilts	11.3 to 18.9
Pregnant sows	11.3 to 22.7
Lactating sows	18.9 to 26.5
Boars	11.3 to 22.7

Table A. 8: Drinking water demand Small ruminants (litres per head) (DAF 2014).

Small ruminants	Daily requirements (l/head)
Adult dry sheep on grassland	2 – 6
Adult dry sheep on saltbush	4 – 12
Ewes with lambs	4 – 10
Weaners	2 – 4

Table A. 9: Drinking water demand cattle when the daily high temperature is 32°C (litres per head (modified from UGA 2012).

Type of Cattle	Daily liters required per 45 kg of body weight
Growing/Finishing Cattle	8
Dry Cow	4
Cow-Calf Pair	8
Bull	4

Table A. 10: Drinking water demand dairy Cattle (litres per head) (modified from OMAFRA 2015).

Dairy Cattle Type	Level of milk production (kg milk/day)	Water requirement range (L/day)
Dairy calves (1-4 months)	-	4.9 – 13.2
Dairy heifers (5-24 months)	-	14.4 – 36.3
Milking cows	13.6	68 – 83
	22.7	87 – 102
	36.3	114 – 136
	45.5	132 – 155
Dry cows	-	34 – 49

Table A. 1: Meat processing impacts associated with processing four different species, expressed as per kilogram of Hot Stand Carcass Weight (HSCW) (Wiedemann and Yan, 2014)

Livestock Species	L/kg HSCW
Chicken meat	2.43
Pork meat	6.57
Sheep meat	7.53
Beef meat	8.75

Appendix 5: Figure on inventory assessment

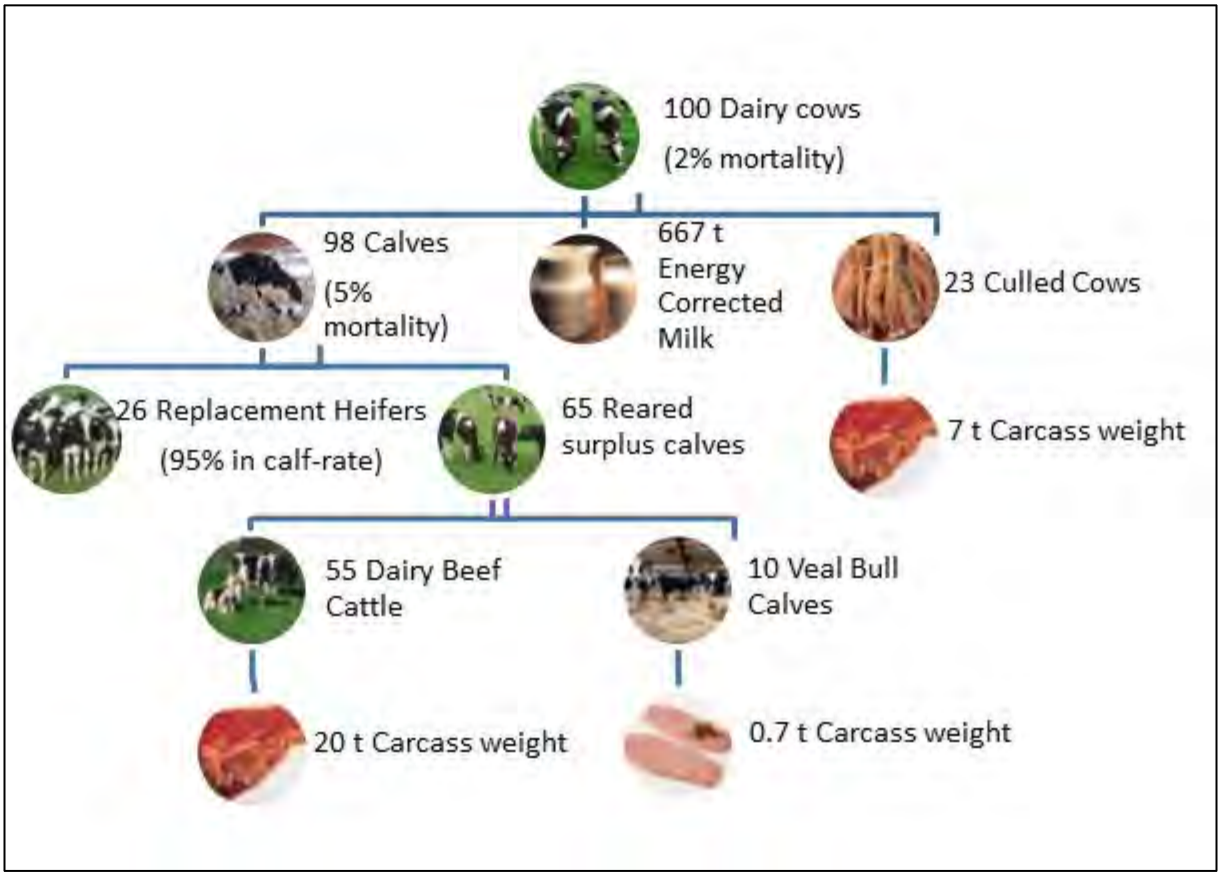

Figure A. 1: Simplified example of a dairy farm illustrating annual flows of animals (dairy cows, replacement heifers and reared surplus calves) and product flows of energy corrected milk (ECM) and meat (carcass weight) (LEAP, 2016a).

Based on breeding cow herd of 100 cows, 100 percent calving, 25 percent replacement rate, 2 percent mortality rate and first calving at 2 years of age. A dressing percentage (carcass weight/live weight) of 50% for culled cows and 59% for Dairy beef and veal bull calves was used. Please note all cows were bred by artificial insemination so breeding bulls were not included in the model.

Appendix 6: Blue water scarcity indicators

Table A. 2: Sample of blue water scarcity indicators (Listed in chronological order of publication).

References	Type of indicator
Falkenmark and Lindh (1974)	Withdrawal-to-availability ratio, with thresholds defined
Raskin et al. (1997)	Withdrawal-to-availability ratio (WTA), with thresholds defined
Water Exploitation Index (WEI) (EEA, 2003)	Withdrawal-to-availability ratio (WTA), with thresholds defined
Water Stress Indicator (WSI) Smakhtin et al. (2004) Mila i Canals et al. (2009)	Withdrawal-to-(availability - EWR) ratio
Use-to-Qxx ratio Alcamo et al. (2007)	consumption-to-Q90 ratio, (with Q90 = discharge that is exceeded 90% of the time per month)
Water Stress Index (WSI) Pfister et al. (2009) Pfister and Bayer (2014)	Based upon the WTA, scaled between 0.01 and 1 Adaptation to monthly level
Swiss Ecological scarcity Frischknecht and Büsser Knöpfel, (2013) Update of Frischknecht et al. (2009)	Based on Withdrawal-to-availability Ratio, converted to eco-points
Use to environmentally available water (Vanham et al., 2009a, b)	Withdrawal/(availability - Q95) ratio, (with Q95 = daily discharge that is exceeded 95% of the month).
Wada et al. (2011)	Withdrawal-to-availability ratio (WTA), with thresholds defined
Water scarcity α Boulay et al. (2011)	Based on Consumption-to-Q90 ratio, modeled between 0 and 1. Option to consider availability of different water qualities.
Blue water scarcity index Hoekstra et al. (2012)	Consumption-to-(availability-EWR) ratio (with EWR = 80% of the total runoff). Distinction: low, moderate, significant, severe blue water scarcity. Monthly level

Loubet et al. (2013)	Based on consumption-to-availability index, integrating downstream effects within watershed
Blue water sustainability index (BlWSI) Wada and Bierkens (2014)	BlWSI = (NRGWA+SWOA)/CBWU, (with NRGWA=Non-renewable groundwater abstraction, CBWU= Consumptive blue water use, SWOA= surface water over-abstraction and EWR=Q90. Dimensionless values between 0 and 1
Water Depletion index (WDI) Berger et al. (2014)	Based on consumption-to availability index, modeled between 0.01 and 1
Agricultural water scarcity Motoshita et al. (2014)	Based on Water Stress Index (WSI) with agricultural use ratio, irrigation dependency and adaptation capacity index of food stock
Water unavailability Yano et al. (2015)	Based on surface and time required to replenish water
Water depletion Brauman et al. (2016)	Fraction of renewable water consumed for human activities
Water Stress Index Scherer and Pfister (2016) Scherer and Pfister (2017)	Accounting for groundwater, surface and total water scarcity separately. Based on WTA and CTA incl. uncertainties
AWARE Boulay et al. (2018)	Inverse of the Available Water Remaining (AWARE) per m^2, with the available water remaining being measured as the total water availability in a catchment minus the human and environmental water demands. Values from 0.1 to 100, related to the world average
WRI Baseline Water Stress (Aqueduct 2018; Kölbel et al., 2018)	Baseline water stress measures the ratio of total annual water withdrawals to total available annual renewable supply, accounting for upstream consumptive use. Higher values indicate more competition among users.

Appendix 7: Decision tree on response options

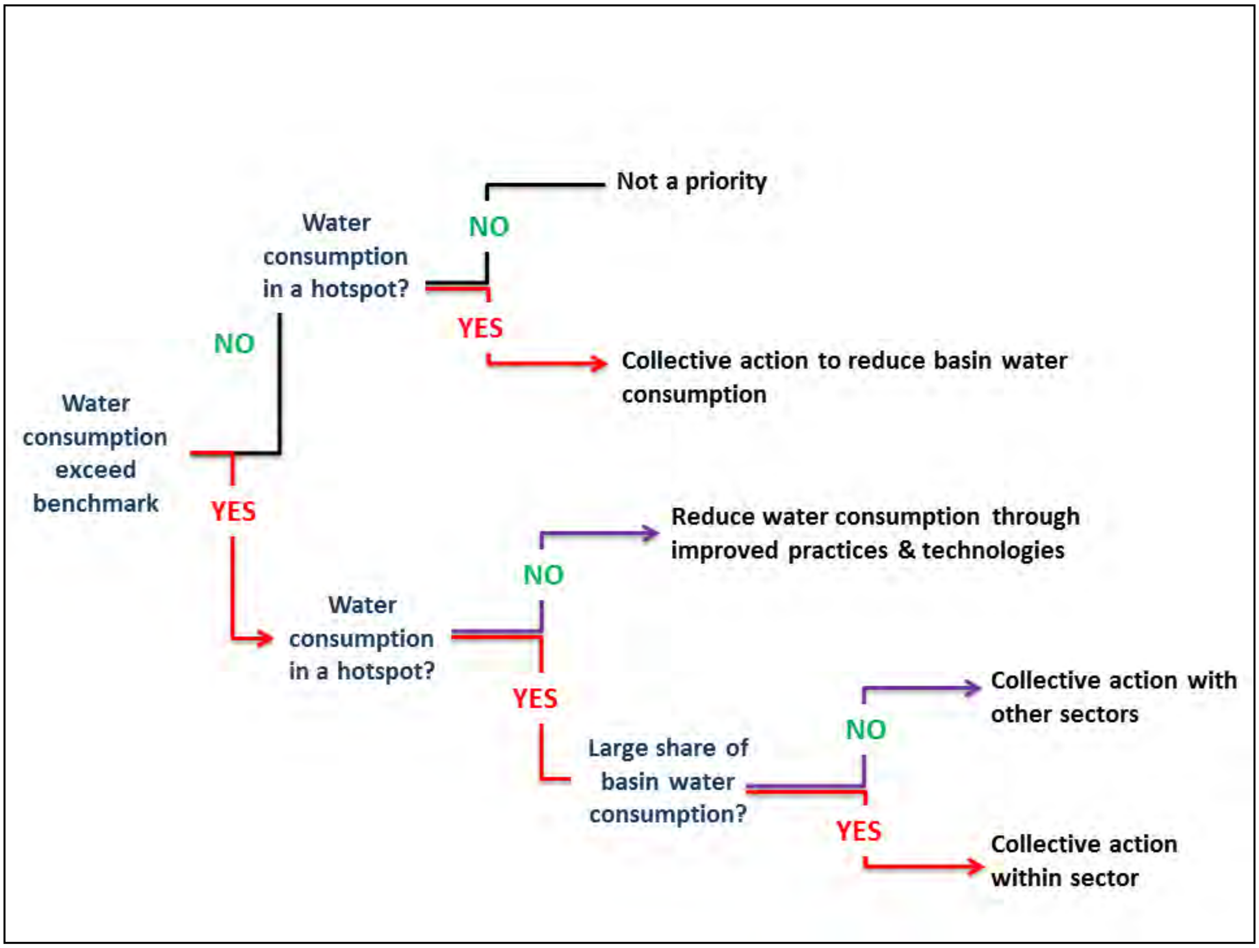

Figure A. 2: Systematic approach for prioritization and identifying types of response options

Appendix 8: Farming measures to increase livestock water productivity

Along the livestock production –consumption chain are many opportunities to improve water productivity, and many options are related indirectly to water. Animal health is one important example to increase overall production, and thereby the water productivity as the animals utilize fodder and other water resources more efficiently.

The variability in water productivity depends on the quality of data used and variation in environmental and crop management conditions. In general, the crop water productivity has increased by at least 100 percent between 1961 and 2001 (Kijne, 2003). The major factor behind this growth has been yield increase. For many crops, the yield increase has occurred without increased water consumption, and sometimes with even less water given the increase in the harvesting index. As a large portion of water consumption of livestock products originates from feed consumption, an increase in crop water productivity is pivotal in increasing the water-related environmental performance of the livestock production system. With respect to water demand in dairy systems, feeding strategies and milk yield optimization are identified by Krauß et al. (2015b) as particularly important measures to raise water productivity substantially on dairy farms. Three main explanatory factors in feeding strategies were identified: the feed conversion efficiency, feed composition, and origin of the feed. Palhares (2014) calculated the water footprint of swines and evaluated the impact of nutritional strategies. Conventional diet had the highest value and the diet with three nutritional strategies the lowest. The reduction was 18% among these diets. For each liter of water used 179 kcal was generated to conventional diet and 218 kcal to three nutritional strategies. Results support that the use of nutritional strategies provides a swine production more conservationist in water use, reducing its water footprint.

Water management practices in feed production

Irrigation efficiency can be increased by reducing the non-productive water losses to include e.g., soil evaporation losses (Hess and Knox, 2013; Perry, 2011). However, many non-productive and non-consumptive losses do not contribute to water consumption. The water consumption of irrigated feed production will only be reduced if irrigation efficiency results in reduced consumptive water use, for example by reducing percolation to a saline aquifer, reducing evaporation losses (soil or spray) or reducing the transpiration of weeds.

Water management practices: In the stable

Most water used in livestock farming is for animal drinking. The amount of water supplied can be reduced by use of water-efficient drinking devices (such as water bowls, bite type drinkers, nipple drinkers or animal operated valves) and maintenance and repair water troughs to eliminate leaks. The use of shade on waiting yards or feed yards, which allows to maintain feces and urine moist reducing the use of water. In addition, this practice is good from animal welfare point of view in hot weather conditions.

There is, however, little scope for savings in water consumption apart from changing the animal's diet or the ambient temperature of animal housing. Relatively simple changes in management practice lead to significant water savings in wash-down water use (Defra, 2009, Drastig 2011);

Increase in water productivity of cleaning processes

- Pre-soaking parlours, yards and housing to loosen dirt before washing
- Scraping yards to remove dirt before washing
- Using high-pressure bulk tank washing systems to save water
- Separate collecting, storing and applying waste water
- High pressure washers e.g. 2,400psi will increase efficiency and reduce water use for cleaning
- Using recycling systems

Reduction of drinking water consumption (with animal welfare as higher priority):

- Maintenance at regular intervals
- Appropriate dimensioning of drinking water installation

Increase in water productivity of cooling processes:

- Circuitry of cooling water
- Productive use of cooling water
- Cooling by spray humidification only up to a certain atmospheric humidity (< 60 %)
- Appropriate nozzles and valves
- Reduction of water-based processes

Increase in water productivity through nutritional managements:

- Diets may be properly formulated in order to avoid excessive water consumption, feed intake and excretion of nutrients;
- Maximizing the use of roughage feeds shall decrease the pressure on freshwater resources;
- Roughage-concentrate ratio and type of roughage are the nutritional aspects that most significantly influence the footprint values to ruminants;
- Use nutritional technologies such as amino acids, enzymes etc. to improve nutrients use efficiencies and animals performance;

Using water from alternative sources can save money and reduce vulnerability to water shortages. Although these may not reduce the water consumption, they may use water from less vulnerable sources and therefore could reduce potentially reduce the impact of water consumption on a specific user. Water can also be saved by recycling after it has been used for another process. However, the opportunities for a recycling depend on the quality of the water after the first use.

The key principles for improving water productivity depend on the production or sub-production systems under consideration and the geographic extent under study (field, farm and basin levels). For instance, water productivity of feed may be improved by: (i) Increasing the marketable yield of the crop for each unit of water transpired, possibly by selecting a more efficient crop variety; (ii) reducing all outflows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop stomatal transpiration; and (iii) increasing the effective use of rainfall, stored water, and water of marginal quality

Appendix 9: Data Quality and relation to uncertainty assessment

Data quality can be limited if secondary data are used (compare section 3 data quality and table 5 on tiered approach). In order to assess the importance of limited data quality, uncertainty assessment can be used. If important water use data (i.e. contributing a lot to the total impact) is of low quality and thus high uncertainty, it should be improved. Since there is various aspects of data quality, a generic approach used in LCA to assess different dimensions of data quality on a qualitative level can be used to derive a quantitative uncertainty estimate (Weidema and Wesnaes, 1996 in: Goedkoop et al., 2016).

This "pedigree matrix" contains the elements presented in Table 4 (section 3). The quality criteria are put in rows and the quality rating in columns as presented in Table A.12. For each criterion, the quality description for the scores 1-5 is provided together with the resulting uncertainty score ranging between 1.00 and 2.00. These scores refer to geometric standard deviation (GSD) used to describe log-normally distributed data. The score represents the $GSD^{1.96}_i$ for each criterion *i*, i.e. the factor to be applied to the mean (μ; expected/estimated value) in order to get the 95% confidence interval: [$\mu / GSD^{1.96}$; $\mu * GSD^{1.96}$]. These scores are also referred to k value (dispersion factor) by Slob (1994) who generalizes this concept also for non-lognormally distirbuted data. The total uncertainty factor of each data point ($GSD^{1.96}_{total}$) is calculated as follows based on the scores in Table A.12:

$$GSD^{1.96}_{total} = \exp\left(\sqrt{\sum_{i=1}^{5} \ln(GSD_i^{1.96})^{2}}\right)$$

Table A. 3: Proposed approach to derive uncertainty from data quality and suitability information based on Weidema and Wesnaes (1996) in Goedkoop et al. (2016).

Score:	1	2	3	4	5
1 Reliability	Verified data based on measurements	Verified data partly based on assumptions OR non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert); data derived from theoretical information (stoichiometry, enthalpy, etc.)	Non-qualified estimate
	1.00	1.05	1.10	1.20	1.50
2 Completeness	Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered OR >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered OR some sites but from shorter periods	Representativeness unknown or data from a small number of sites AND from shorter periods
	1.00	1.02	1.05	1.10	1.20
3 Temporal correlation	Less than 3 years of difference to our reference year	Less than 6 years of difference to our reference year	Less than 10 years of difference to our reference year	Less than 15 years of difference to our reference year	Age of data unknown or more than 15 years of difference to our reference year
	1.00	1.03	1.10	1.20	1.50
4 Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from smaller area than area under study, or from similar area	Data from area with slightly similar produc-tion conditions	Data from unknown OR distinctly different area (north America instead of Middle East, OECD-Europe instead of Russia)
	1.00	1.001	1.02	1.05	1.10
5 Further technological correlation	Data from enterprises, processes and materials under study (i.e. identical technology)	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data on related processes or materials but same technology, OR data from processes and materials under study but from different technology	Data on related processes or materials but different technology, OR data on laboratory scale processes and same technology	Data on related processes or materials but on laboratory scale of different technology
	1.00	1.05	1.20	1.50	2.00

http://www.fao.org/partnerships/leap