VERSION 1

Water use in livestock production systems and supply chains

Guidelines for assessment

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Foreword

These guidelines are a product of the Livestock Environmental Assessment and Performance (LEAP) Partnership, a multi-stakeholder initiative whose goal is to improve the environmental sustainability of livestock supply chains through better methods, metrics and data.

Water is essential to life and crucial for agricultural food production. During the last century, irrigation played an important role in increasing and stabilizing crop yields leading to significant improvements in food security and nutrition in many countries. According to OECD (2010), approximately 70 percent of global freshwater withdrawal is used in agriculture, and a large share goes on feed and livestock production (Opio *et al*., 2011).

The growth of the world population is increasing the competition between sectors, users and regions. There is an urgent need to improve the understanding of global water supply and demand in livestock production, as well as the resource efficiency.

The goal of the methodology developed in these guidelines is to introduce a harmonized international approach for assessing livestock production systems and supply chains. This work aimed at building consensus for water use assessment in order to report blue water scarcity footprints and to identify actions for improvement in water management. Overlooking or miscounting water use has often resulted in misinterpretation of the water footprint of livestock products and also in setting sustainable dietary recommendations. Furthermore, assessing water use is essential to monitor progress towards some of the Goals of the Agenda 2030 for Sustainable Development.

The objectives of these guidelines are:

- To develop a harmonized, science-based approach resting on a consensus among the sector's stakeholders;
- To recommend scientific, but at the same time practical, approaches that build on existing or developing methodologies;
- To promote harmonised approaches to assess water flows, relevant for global livestock supply chains;
- To identify the principal areas where ambiguity or differing views exist concerning the methodological framework.

During the development process, these guidelines were submitted for technical review and public review. The purpose was to strengthen the advice provided and ensure the technical document meets the needs of those seeking to improve environmental performance through sound assessment practice. This document is not intended to remain static. It will be updated and improved as the sector evolves and more stakeholders become involved in LEAP, and as new methods and data become available. The guidelines developed by the LEAP Partnership gain strength because they represent a multi-actor coordinated cross-sectoral and international effort to harmonize environmental assessment approaches. Ideally, the harmonization leads to greater understanding, transparent application and communication of metrics, and, not least, real and measurable improvement in environmental performance.

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The Technical Advisory Group (TAG) for Water Use Assessment (Water TAG) conducted the background research and developed the core technical content of the guidelines. The Water TAG comprised: Anne-Marie Boulay (Co-Chair), Interdisciplinary Research Laboratory in Sustainable Engineering and Eco-design (LIRIDE), Sherbrooke University and International Reference Centre for the Lifecycle of Products, Processes and Services (CIRAIG), Polytechnique Montréal, Canada; Katrin Drastig, (Co-Chair), Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB), Germany; Stephan Pfister (Technical Supervisor), ETH Zurich, Switzerland. Members of the Water TAG included: Alessandro Manzardo, Centre of Research of Environmental Quality, University of Padua, Italy; Amanullah, University of Agriculture Peshawar, Pakistan; Arjen Hoekstra, University of Twente, Netherlands and National University of Singapore, Singapore; Armelle Gac, French Livestock Institute; Ashok Chapagain, University of the Free State, South Africa; Aung Moe, Alberta Agriculture and Forestry, Canada; Barbara Civit, National Scientific and Technical Research Council (CONICET) National Technological University, Mendoza Regional School (UTN–FRM), Argentina; Brad Ridoutt, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia; Davy Vanham, European Commission, Joint Research Centre (JRC), Italy; Ernesto Reyes, Agribenchmark, Germany; Giacomo Pirlo, Centre of Research for Forage and Dairy Production, Council for Agricultural Research and Agricultural Economy Analysis (CREA), Rome, Italy; Gloria Salmoral, University of Exeter, United Kingdom; Julio Cesar Pascale Palhares, Brazilian Agricultural Research Corporation (EMBRAPA) Southeast Livestock, Brazil; Liu Junguo, South University of Science and Technology of China; Maite Aldaya, United Nations Environment Programme (UNEP), Public University of Navarre, Spain; Marlos De Souza, Land and Water Division, FAO; Masaharu Motoshita, National Institute of Advanced Industrial Science and Technology, Japan; Michael Lathuillière, University of British Columbia, Canada and Stockholm Environment Institute, Sweden; Ranvir Singh, Soil and Earth Sciences Group, Massey University, New Zealand; Ricardo Morales, AgroDer, Mexico; Ridha Ibidhi, National Institute of Agricultural Research of Tunisia; Sophie Bertrand, International Dairy Federation, National Interprofessional Centre for Dairy Economics (IDF–CNIEL), France; Steve Wiedemann, University of New England, Integrity Ag and Environment, Australia; Tim Hess, Cranfield University, United Kingdom; Tim McAllister, Agriculture and Agri-Food Canada; Valentina Russo, University of Cape Town, South Africa; Veronica Charlon, National Institute of Agricultural Technology Agricultural Experimental Station (INTA-EEA) Rafaela, Argentina; Weichao Zheng, China Agricultural University.

The conclusions and statements presented are those of the authors and may not in any circumstances be regarded as stating an official position of FAO, the European Commission (EC) or other organizations.

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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, comprised: Carolyn Opio (Coordinator), Camillo De Camillis (LEAP Manager), Félix Teillard (Technical Officer), Aimable Uwizeye (Technical Officer), Juliana Lopes (FAO), until December 2017) and Maria Soledad Fernandez Gonzalez (FAO).

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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.

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Multi-step review process

The initial draft guidelines developed by the TAG over 2016 and 2017 went through an external peer review before being revised and submitted for public review. Jennie Barron (IWMI, International Water Management Institute, Sweden), Jing Huang (Southwest University of Science and Technology, China), Nydia Suppen Reynaga (ISO, ISO/TC 207/SC 5 (ISO 14046), vice-chair person, Centro de analisis de cyclo de vida y diseno sustentable, Mexico), Francisco Javier Salazar (Instituto de Investigaciones Agropecuarias, INIA, Chile), Mats Lannerstad (former focal point for Water, Land and Ecosystems at ILRI, the International Livestock Research Institute) peer reviewed these guidelines in early 2018. The LEAP Secretariat reviewed this technical guidance before and after 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. The following provided feedback: FAO Climate, Biodiversity, Land and Water Department (CBL); the Netherlands; New Zealand; the International Poultry Council; the International Dairy Federation; the International Wool land Textile Organization; National Cattlemen's Beef Association, USA; AgResearch Limited, New Zealand; Wageningen UR, Livestock Research, the Netherlands; and WWF. The public review started from 23rd May 2018 and lasted until 22nd August 2018. The review period was also announced to the public through an article published on the FAO website. The scienti¬fic community working on life cycle assessment and water footprinting was alerted through the LCA list held by PRé Consultants, the technical advisory board of the EC's Product Environmental Footprint, and through the IDF SCENV. Experts in water productivity, water footprinting, life cycle assessment, environmental footprintng were informed through mailing lists, announcements, articles in social networks, and newsletters. FAO of¬ficers were encouraged to participate in the public review through the FAO Livestock Technical Network Newsletter and through invitations to the FAO Climate, Biodiversity, Land and Water Department (CB). The LEAP Secretariat also publicized the 2018 LEAP public review through invitations to the Life Cycle Initiative and oral speeches in international scienti¬fic conferences and meetings, including those arranged by the Global Agenda for Sustainable Livestock, World Farmers' Organization, and the European Commission's Product Environmental Footprint. An advanced draft was presented in the Food LCA 2018 in Bangkok, Thailand. The following have participated in the public review and contributed to improving the quality of this technical document: Australia, Amanullah (Dept Agronomy, The University of Agriculture Peshawar, Parkistan), Brenna Grant (Canfax Research Services, Canadian Cattlemen's Association), and María Sánchez Mainar (IDF).

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Abbreviations and acronyms

ATB	Leibniz Institute for Agricultural Engineering and Bioeconomy
AWARE	Available WAter REmaining
BWSI	Blue Water Scarcity Index
CF	Characterization factor
CW	Carcass weight
DG	Directorate General
DW	Dressed weight
EC	European Commission
EEA	European Environmental Agency
ET	Evapotranspiration
EWR	Environmental water requirement
FAO	Food and Agriculture Organization of the United Nations
FPCM	Fat and protein corrected milk
FU	Functional unit
GASL	Global Agenda for Sustainable Livestock
HWC	Human water consumption
IDF	International Dairy Federation
IFIF	International Feed Industry Federation
IMS	International Meat Secretariat
IPC	International Poultry Council
ISO	International Organization for Standardization
IWTO	International Wool Textile Organization
LCA	Life cycle assessment
LCI	Life cycle inventory
LEAP	Livestock Environmental Assessment and Performance
LW	Live weight
MICCA	Mitigation of Climate Change in Agriculture
OECD	Organisation for Economic Co-operation and Development
RF	Reference flow
SDG	Sustainable Development Goal
SETAC	Society of Environmental Toxicology and Chemistry
TAG	Technical Advisory Group
UECBV	European Livestock and Meat Trading Union
UNEP	United Nations Environment Programme
WAMIP	World Alliance of Mobile Indigenous Peoples
Water TAG	Technical Advisory Group on water use assessment
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WP	Water productivity
WRI	World Resources Institute
WSF	Water scarcity footprint
WWF	World Wide Fund for Nature

Glossary

TERMS RELATING TO FEED AND FOOD SUPPLY CHAINS

Abattoir	Animal slaughterhouse.
Arable land	Land on which the vegetation is dominated by production of field crops (e.g. maize, wheat and soybean).
Cultivation	Activities related to the propagation, growing and harvesting of plants including activities to create favourable conditions for their growth.
Feed	Any single or multiple materials, whether processed, semi-processed or raw, which are intended to be fed directly to food-producing animals (FAO/WHO, 2008).
Fodder	Forage harvested from both cultivated and non-cultivated land, fed intact to livestock, including fresh and dried forage.
Silage	Forage harvested and preserved (at high moisture content generally > 500 g/kg) 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 systems of keeping animals and the most common in developing countries, in both urban and rural areas. They are typically semi-intensive production. Backyard systems are the most basic traditional system of keeping pigs and the most common in Asian and African countries.
Beef	Culinary name for meat from bovines, especially domestic cattle, although also refers to meat from the other bovines: antelope, African buffalo, bison, water buffalo and yak.
Broiler	Chicken reared for meat.

Buffalo (and other Bovinae)	Popularly known as water buffalo or domestic Asian water buffalo (*Bubalus bubalis*), a large member of the Bovidae family, it originated in India and is found on the Indian subcontinent, and in Viet Nam, Peninsular Malaysia, Sri Lanka, the Philippines and Borneo. Used as draught animals and suitable for milk production. Also known as carabao. In addition, Bovinae are also found in North America and are known as American bison (*Bison bison*). Bisons also live 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 (DW) of the animal	Weight after slaughter and removal of most internal organs, head (cattle and poultry) and skin (ruminants).
Cow	Mature female of a bovine animal.
Dairy farm	Agricultural facility to raise and maintain animals for the harvesting and/or processing of animal milk – mostly from cows or goats, but also from buffaloes, sheep, horses or camels – for human consumption.
Extensive farming system	Low-input, low-output – and consequently low-intensity – system using small inputs of labour, fertilizers and capital, relative to the land area being farmed. In less developed regions, they are often small-scale and mixed cropping subsistence farming systems. In more/hightly developed regions, they are often grassland-based farming systems, such cattle and sheep grazing.
Flock	Group of poultry.
FPCM	Fat and protein corrected milk (kg).
Grasslands	Large open area of country covered with grass, particularly when 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 < 200 g/kg.
Herd	Group of bovines.

Heifer	Young cow – normally over one year old – that has not produced a calf.
Hide	Skin of a large animal, such as a cow or buffalo, which can be used for making leather.
Intensive farming system	High-input, high-output – and consequently high-intensity – system using large inputs of labour, fertilizers and capital. It is geographically concentrated, commercially oriented and associated with specialized production.
Meat	Fresh, chilled or frozen edible carcass, including offal, derived from food animals.
Mixed crop–livestock system	Combination of crop and livestock activities in a production system.
Replacement rate	Percentage of adult animals in the herd replaced by younger adult animals each year.
Ruminant	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, 2006a, 3.17).
Animal perspiration	Processing or sweating that assists in regulation of body temperature through evaporative cooling.
Background process	Processes on which no influence or, at best, only indirect influence may be exercised by the decision-maker for which an LCA is carried out (UNEP, SETAC and Life Cycle Initiative, 2011), herein referred to as "indirect" (see "Indirect water" below).
Biomass	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 microorganisms.

Blue water — Freshwater flows originating from run-off 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, is the result of hydrological events (e.g. flooding), or comes 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.

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. Examples include equipment, machinery, buildings, facilities and vehicles (WRI and WBCSD, 2013).

Characterization factor — Factor derived from a characterization model applied to convert an assigned life cycle inventory (LCI) analysis result to the common unit of the category indicator (ISO, 2006a, 3.37). The characterization factor represents the degree of impact (on the relevant category indicator) per unit of inventory, such as the increase in local water scarcity per m^3 of water consumed. Therefore, the values in the LCI 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, 2006a, 3.6).

Co-product — Product from a plant cultivation system that can be used either 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 that are of primary objective and with higher financial value (ISO, 2006a, 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, 2006a, 3.45).

Crop coefficient Plant parameter used in predicting evapotranspiration (ET). The crop coefficient, Kc, is the ratio of evapotranspiration observed for the crop (ETc) over the reference evapotranspiration (ET0) 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, 2006a, 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 is direct. If the study refers to a business (e.g. a dairy), water consumption within the factory is direct. Conversely, indirect water consumption (background) is outside the control of the focus of the study (e.g. water consumption in the supply chain of inputs).

Downstream Life cycle assessment (LCA) terminology: Occurring along a product supply chain after the point of referral. (EC, 2013).

HYDROLOGIC TERMINOLOGY: DIRECTION IN WHICH A FLUID IS MOVING

Drainage basin Area from which direct surface run-off from precipitation drains by gravity into a stream or other water body (ISO, 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 BSI, 2011, 3.17). *Note:* When barter is in place, the economic value of the commodity traded can be calculated based on the market value and the amount of commodity exchanged.

Effective rainfall Also known as effective precipitation (P_e), the fraction of the total amount of rainwater that is retained in the root zone and can be used by plants. It is calculated as: *total rainfall* – (*evaporation* + *run-off* + *deep percolation*).

Effective irrigation The fraction of the total amount of irrigation applied that is retained in the root zone and used by plants. It is calculated as: total irrigation applied – (*evaporation* + *run-off* + *deep percolation*).

Elementary flow	Material or energy entering the system under study that has been drawn from the environment without previous human transformation, or material or energy leaving the system under study that is released into the environment without subsequent human transformation (ISO, 2006a, 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, 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 (ET)	Quantity of water transferred from the soil to the atmosphere by evaporation and plant transpiration.
Foreground system	See "Direct water" above.
Functional unit	Quantified performance of a product system for use as a reference unit (ISO, 2006a, 3.20).
Green water	Precipitation that is stored as soil moisture and eventually transpired or evaporated.
Indirect water	Indirect water consumption (background) is outside 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, 2006a, 3.39). Examples: water scarcity, human toxicity.
Infrastructure	Capital goods.
Input	Product, material or energy flow that enters a unit process (ISO, 2006a, 3.21).
Land use change	Change in the purpose for which land is used by humans (e.g. cropland, grassland, forestland, wetland, industrial land) (BSI, 2011, 3.27).

Life cycle assessment Compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (ISO, 2006a, 3.2).

Life Cycle Inventory See "Water inventory" below.

Precipitation Liquid or solid products of the condensation of water vapour falling from clouds or deposited from air on the ground.

Primary data Quantified value of a unit process or activity obtained from a direct measurement or from a calculation based on direct measurements at its original source (ISO, 2014, 3.6.1).

Product(s) Any goods or service (ISO, 2006a, 3.9). Example: 1 litre of milk for consumer consumption.

Product system Collection of unit processes with elementary and product flows, performing one or more defined functions and modelling the life cycle of a product (ISO, 2006a, 3.28).

Raw material Primary or secondary material used to produce a product (ISO, 2006a, 3.1.5). Example: feed crop.

Reference flow Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit (ISO, 2006a, 3.29). Example: 1 litre 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).

Run-off Part of the precipitation that flows towards a river on the ground surface (surface run-off) or within the soil (subsurface run-off 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, 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, 2006a, 3.31).

Sewer	Channel, drain for waste water.
System boundary	Set of criteria specifying which unit processes are part of a product system (ISO, 2006a, 3.32). Examples: field, farm, basin/catchment.
Tier	Categorization unit of uncertainty assessment depending on scale of analysis and data availability/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, 2006a, 3.34).
Water body	Entity of water with definite hydrological, hydrogeomorphological, physical, chemical and biological characteristics in a given geographical area. Examples: aquifer, lake, river, groundwater, sea, iceberg, glacier and reservoir. *Note:* 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, 2014, 3.1.7).
Water consumption	A form of water use. The term is often used to describe 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. Change in evaporation caused by land-use change is considered [a form of blue] water consumption (e.g. reservoir) (ISO, 2014, 3.2.1). Consumptive water use has the same meaning. Water consumption can refer to blue and/or green water. All water evapotranspired is considered consumed. It has to be noted that consumed water enters the water cycle as long as it is not chemically transformed.
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 ISO, 2014, 3.3.2). Water inputs refer to blue and/or green water. In some cases, water accounting is used as a synonym for water inventory.
Water scarcity footprint (WSF)	Metric that quantifies the potential environmental impacts related to water scarcity (based on ISO, 2014).

Water use	Use of water by human activity (ISO, 2014, 3.2.1).
Water withdrawal	Anthropogenic removal of water from any water body or from any drainage basin, either permanently or temporarily (ISO, 2014, 3.2.2).
Metabolic water production	Formation of water 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 (examples of product units: 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 m^3) calculated for a specific process, unit or stage, including only the direct water consumed (see "Direct water" above). The goal of this metric is to identify potential improvements in direct water use per output unit of the system assessed as a means 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 process or life cycle stage. 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, 2014).

Executive summary

The Technical Advisory Group (TAG) for Water Use Assessment has developed guidelines on water footprinting for livestock supply chains. The mandate of the Water TAG was to: i) provide recommendations to monitor the environmental performance of feed and livestock supply chains over time so that progress towards improvement targets can be measured; ii) apply the guidelines for feed and water demand of small ruminants, poultry, large ruminants and pig supply chains; iii) build on and go beyond the existing FAO LEAP guidelines; and iv) pursue alignment with relevant International Organization for Standardization (ISO) standards, specifically ISO 14040, ISO 14044 (ISO, 2006b and 2006a) and ISO 14046 (ISO, 2014).

The group comprises 30 international experts who met for two workshops organized in Rome, Italy and Kigali, Rwanda for consensus building on the different aspects related to water use and its potential impacts on livestock supply chains. Several online meetings on specific topics were subsequently held to finalize consensus and address all the members' comments. The guidelines on water use assessment include the impact assessment: the assessment of the environmental performance related to water use 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 (ISO, 2014); and the assessment of the system's productivity of green and blue water.

The following table summarizes the major recommendations for assessing potential environmental impacts of blue water consumption following the water scarcity footprint and the productivity of green and blue water in livestock supply chains. It provides a condensed overview and guides the reader to the location of specific guidance within the document.

All LEAP guidance documents use a normative language to indicate which provisions of the guidelines are requirements, which are recommendations, and which are permissible or allowable options that the intended user may choose to follow. The term "shall" is used in this guidance to indicate what is required. 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. In addition, as a general rule, assessments and guidelines claiming to be aligned with the present LEAP guidelines should flag and justify with reasoning any deviations.

Topic	Summary	Section
INTRODUCTION		
Scope of the guidelines	To present principles, requirements and guidelines of water use assessment associated with livestock production and products.	1.2.1
Objective of the guidelines	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.	1.2.2
SCOPE		
Goal of the water use assessment	To reveal potential to improve the overall performance of the system in terms of water consumption by considering a combination of the water productivity (WP) metric and water scarcity footprint (WSF).	2.1
Goal of the water scarcity impact assessment	To evaluate the contribution of an activity (e.g. livestock production) to water scarcity and the related potential environmental impacts resulting from deprivation of other human or ecosystem water users, including supply chain water consumption (e.g. feed).	2.1.1
Goal of the water productivity assessment	To assist farmers to optimize the water flows in their farms and to develop water use through agronomic measures and farm management.	2.1.2
Characterization of livestock production systems	Essential, because resource utilization in general and water use in particular are closely connected to the production method. To estimate water use, the volume and nature of the water used with each of the livestock species shall be determined. This includes consumptive uses for each of the livestock species in a mixed production system.	2.2.1
System boundary	Represents the cradle-to-primary processing stages of the life cycle of the main products from livestock. It covers the main stages: cradle-to-farm gate; transportation of animals to primary processing facility; and primary processing.	2.3
Functional units and reference flow	Functional unit describes the function(s) delivered by a system in a quantitative way. Reference flow refers to the "measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit" (ISO, 2006a).	2.4
Geographical and spatial coverage and distribution of the study	For a water use assessment, the smallest spatial resolution considered is the watershed (~100–1 000 km^2); for a water productivity assessment, coverage may be at field level (< 0.5 km^2).	2.6
Water consumption (feed production, drinking, servicing, processing)	The water consumption data considered depends on the scope of the water use assessment performed; for example, if a water productivity assessment (e.g. WPdirect) is included, the data may be more limited in scope. The general recommendation is to assess both direct and indirect water consumption, since indirect water consumption may be much greater than direct water consumption.	2.8
General principles for data quality	When evaluating the data collection requirements for a project, it is necessary to consider the influence of the project scope. In general, the guidelines recommend collection of primary data for foreground processes, which are generally considered to be under the control or direct influence of the study commissioner.	3.1
Data types and sources: data identification	Two types of data may be collected for and used in water use assessments: primary and secondary.	3.2
Data quality	Practitioners shall assess data quality by using data quality indicators as described in these guidelines.	3.2.2
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 are crucial for the proper interpretation, reporting and communication of results.	3.3.1
Uncertainties related to benchmarking	Water consumption of crops varies enormously across and within regions, leading to high levels of uncertainty in regional benchmarking. Although global benchmarks are not yet within reach, metrics in these guidelines could be used for performance tracking.	3.3.2
Data proxies	The impact of proxy data (if used) on the uncertainty of the model shall be determined and discussed in the study.	3.4

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Topic	Summary	Section
WATER USE INVENTORY		
Overview	As with any inventory exercise, the steps involved are: data collection; 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 the data, ensuring all significant processes, inputs and outputs are included within the system boundary.	4.1
Production systems	These guidelines are intended to be relevant to large ruminant production systems, small ruminant productions systems, pig production systems and poultry production systems.	4.2
Defining feeds or feeding stuff	Feed denotes any single or multiple materials, whether processed, semi-processed or raw, intended for feeding directly to animals.	4.3
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, i.e. input and output (flows) that cross the system boundary. In accordance with ISO 14046 (ISO, 2014), the elementary flows are listed with definitions of the following: quantity of water used, resource type (e.g. precipitation, surface water, seawater), types of usage (evaporation, transpiration, incorporation, return, consumption etc.), and temporal and geographical aspects. Typically, the results of a water balance are reported relative to the reference flow appropriate for a particular process, for example, per tonne of grain (in a feed system).	4.4.1
Calculation of crop water consumption	The crop water consumption 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.	4.4.2
Indirect water in feed production	Where available, crop production data should be obtained from local or regional data sources, taking into account fluctuations in yearly averages. If such data are not available, 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.	4.4.3
Diet composition and feed intake	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.	4.5.1
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 and eggs).	4.5.2
Drinking and cleaning water	Flows within the animal can be modelled in order to accurately partition inflows and outflows using an animal water balance model. Examples of typical ranges in drinking water by livestock and poultry are provided in these guidelines.	4.5.3
Housing water balances	If farm water use is not metered, algorithms for the calculation of water flows in animal production can be used.	4.5.4
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.	4.5.6
Animal product processing	Processing of livestock products typically requires a small but significant proportion of blue water, and it shall therefore be included in water use inventory estimates. A range of water use estimates for the processing of various meat sources is provided in these guidelines.	4.6

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Topic	Summary	Section
ASSESSMENT: WATER SCARCITY IMPACT		
Introduction	Impact assessment provides additional information to interpret the different potential contributions to environmental impacts for the target livestock along the life cycle. The results allow comparison of water consumption impacts across regions.	5.1
Selection of impact categories	In these guidelines, only quantity aspects are discussed. In the calculation of the impact category "water scarcity" (ISO 14046), a scarcity index is used, which results in a category indicator generally representing the potential impacts of depriving users in an area of water resources (ISO, 2014). In most cases, the index is continuous, allowing for a range of levels of scarcity; in some cases a binary approach is adopted, using a value of 1 when demand is greater than availability and 0 when not.	5.2
Selection of category indicators and impact assessment models	Several scarcity impact assessment methods and approaches exist to assess potential impacts associated with scarcity. The AWARE method (Available WAter REmaining) and Blue Water Scarcity Index (BWSI) are recommended in these guidelines.	5.3
Water scarcity impact assessment	The AWARE method provides factors between 0.1 and 100 m^3world eq./m^3 consumed and the BWSI allows to identify regions where BWSI > 1. Both methods assess water scarcity on a localized spatial scale, on a monthly basis, and account for the flows required to remain in the river to sustain flow-dependent ecosystems and livelihoods. This provides a picture of water scarcity highlighting the variability of water scarcity during the year, which might be underestimated when measured or averaged at a full basin scale and on an annual level. While both methods use the three parameters: 1) human water consumption, 2) water availability and 3) environmental water requirement (EWR), the latter term is assessed differently.	5.4
Additional methods and sensitivity analysis	In addition to the two recommended methods, additional methods for water scarcity impact assessment may be used as part of sensitivity analyses to provide useful information on the choice of method. Alternative methods are listed in these guidelines.	5.5
Assessment of water scarcity impacts	The result of the impact assessment using the AWARE model quantifies – for 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, taking into account the potential to deprive other users. For BWSI > 1, 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 < 1 or not, corresponding to the multiplication of the inventory flow with a characterization factor (CF) of 1 or 0, respectively.	5.6
Important aspects in impact assessment	Water use impact assessments are primarily carried out on a catchment scale, i.e. covering the extent of land sharing a common drainage basin and the scale at which agriculture impacts water scarcity. Most water monitoring and reporting programmes operate on a catchment scale; however, modelling of an activity in order to calculate emissions is done on a farm scale.Where land-use change or land management lead to an increase in evaporation or transpiration or the diversion of green water flows, the result may be a decrease in drainage and run-off 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 are recommended.	5.7
Working towards impact assessment of green water consumption	Where a livestock production system leads to a change in green water flows compared with an alternative land use or land management system, water use impact assessment may be considered for this difference, subject to the precautions described.	5.8

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Topic	Summary	Section
ASSESSMENT: WATER PRODUCTIVITY		
Calculating water productivity	Water productivity (WP) is a measure relating the livestock product system value (e.g. kg of meat, litres of milk, number of eggs, calories or protein content in the case of food products, and economic value) to its water consumption. Depending on direct and indirect water needed for production, direct water productivity (WPdirect) and direct + indirect water productivity (WPdirect+indirect) shall be distinguished. To provide an idea of 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/m^3]).	6.1
Calculating feed water productivity	Feed crop WP shall be estimated by the ratio of the yield of the field and the evapotranspiration (ET) from the field from harvest of the previous crop until 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). The mass of feed eaten by the livestock should be estimated for the productivity assessment – the actual pasture intake is relevant.	6.2
INTERPRETATION OF RESULTS		
Interpretation of the results related to impact assessment	The water use impact assessment results provide insight into the potential environmental impacts associated with water consumption for livestock production and livestock products in terms of the physical water quantity.	7.1
Interpretation of the results of the water productivity analysis	Water productivity can be calculated for the whole farm, for feed crops and for livestock. Water productivity for the whole farm varies among different farming systems closely related to differences in farmers' livelihood strategies of the respective livestock or poultry systems. Feed, age, breed and herd structure account for variability in WP. There can also be marked variation between and within the feed crops.	7.2
Analysis of irrigation scheme	One important aspect regarding irrigation practices is the distinction between the fraction that is consumed (including beneficial and non-beneficial) and the fraction that is not consumed (including recoverable and non-recoverable). The irrigation water actually used to produce biomass is relevant. The efficiency of an irrigation scheme can be increased by reducing the non-productive water losses, such as soil evaporation losses.	7.2.1
Comparison of water productivity assessment results	Benchmark comparison should consider the same production conditions: agricultural (climate, soil, genetics and farming practices) and animal-related (production system, climate, genetics, nutritional management, type of barns, and technologies and practices for servicing water). It should be clearly indicated when these parameters are not fully comparable. Comparison with different productive contexts will result in interpretation mistakes and cannot be applied when proposing mitigation practices.	7.2.2
Identification of response options	The interpretation of results should highlight and help detect areas of opportunity where livestock production should be adapted (increased efficiency) or where mitigation measures could be applied within the production chain.	7.2.3
Uncertainty and sensitivity assessment	Uncertainty information of input data needs to be carefully evaluated, as 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 characterized by a high level of uncertainty and a lack of detailed differentiation of affected water bodies (e.g. ground and surface water).	7.3

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Topic	Summary	Section
REPORTING		
General principles for reporting	Reporting conveys information that is relevant and reliable in terms of addressing environmental areas of concern (adapted from ISO 14026 – ISO, 2017).	8.1
General requirements	Reporting of impacts and water productivity assessment results shall be performed without bias and in line with the goal and scope of the study.	8.2
General guidelines for report content	According to the goal and scope of the study, the internal report may include impact and/or water productivity assessment results. The water productivity metric, including both direct and indirect water consumption, is always accompanied by a water scarcity footprint.	8.3
Third party reporting	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 shall be clearly stated in the third party report.	8.4

PART 1

OVERVIEW AND GENERAL PRINCIPLES

1. Introduction

Water is essential to life and a crucial factor in agricultural food production. OECD (2010) reported that around 70 percent of global freshwater withdrawal is used by agriculture. During the last century, irrigation played an important role in increasing and stabilizing crop yields; together with the "green revolution", it has led to the improvement of nutritional alimentation in many countries (Rosegrant, Cai and Cline, 2002). The livestock sector is already a major user of natural resources such as land and water, and currently utilizes about 35 percent of total cropland and about 20 percent of blue water for feed production (Opio, Gerber and Steinfeld, 2011). Deutsch *et al*. (2010) estimated that the livestock sector uses an equivalent of 11 900 km^3 of fresh water annually, that is approximately 10 percent of the annual global water flows (estimated at 111 000 km^3). Weindl *et al*. (2017) estimated that for 2010, 2 290 km^3 of green water and 370 km^3 of blue water were attributed to feed production on cropland. An initial comparison of a range of different models confirms that green water use in global crop production is about four to five 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 the world population (forecast to reach 10 billion in 2050) will result in available freshwater resources being reduced by half to 6 300 m^3 per capita by the mid twenty-first century (Lutz, Sanderson and Scherbov, 1997; Ringler *et al*., 2010). The larger world population will lead to a general food increase of 70–90 percent by 2050 (Rosegrant and Cline, 2003).

There is increasing recognition of the growing competition between users, sectors and uses; it is, therefore, vital to understand the distribution of and demands for fresh water in livestock production (Busscher, 2012; Ridoutt *et al*., 2014; Hoekstra *et al*., 2012). Water usage for the livestock sector should be considered an integral part of agricultural water resource management, taking into account 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 different countries (Schlink, Nguyen and Viljoen, 2010). For example, for every litre of milk produced, a cow needs to drink at least three litres of water (Krauß *et al*., 2016). For high-performing cows, the water requirement corresponds to 150 litres of water per day, and a reduction in drinking water consumption correlates with a drop 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 use inventory" in Part 2, Chapter 4). Livestock production is a complex process, characterized by a wide variety of production practices and systems, some of which rely on a broad range of inputs in order to function.

To improve insight into the demand for fresh water in a specific region and to enhance the performance of individual farms and of the whole supply chain, water consumption studies must include detailed farm-level data relative to climate, agricultural practices and utilization of feed (Jeswani and Azapagic, 2011; Krauß *et al.*, 2015; Ridoutt and Huang, 2012). Therefore, the Livestock Environmental Assessment and Performance Partnership (LEAP) was created in 2012 with a mandate to compile assessment guidelines that can be recognized and used by all relevant stakeholders. The 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. The guidelines are thus intended to support the optimization of use of water resources and the identification of opportunities to decrease the potential impacts of water use in livestock production.

The mandate of the Water TAG was to develop LEAP guidelines on water footprinting that meet the following objectives:

- 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.
- Apply to the feed and water demand of poultry, pig, small ruminant and large ruminant supply chains.
- Build on and go beyond existing FAO LEAP guidelines.
- Pursue alignment with relevant international standards, specifically ISO 14040, ISO 14044 and ISO 14046.

The Water TAG guidance is relevant for livestock production systems, including feed production from croplands and grasslands, and production and processing of livestock products (cradle-to-gate). It addresses all livestock production systems and livestock species considered in existing LEAP animal guidelines: poultry, pig, small ruminant and large ruminant supply chains.

1.1 NEED FOR QUANTITATIVE INDICATORS

There is a need for widely recognized frameworks to assess the performance of livestock and livestock products in order to mitigate negative impacts on water resources. Historically, two methodologies have existed, providing guidelines and indicators for water footprinting (Boulay, Hoekstra and Vionnet, 2013). The present guidelines point towards aspects of these methodologies (Hoekstra *et al.*, 2011; ISO, 2014) in various sections and with specific recommendations. Potential environmental impacts associated with water use are assessed following the ISO 14046 standard with a focus on water scarcity footprint (ISO, 2014). Water productivity metrics are described based on the methods of Molden (1997), Molden *et al.* (1998), Molden and Sakthivadivel (1999), Descheemaker, Amede and Haileselassie (2010), and Prochnow *et al.* (2012) and on the guidelines from the *Water footprint assessment manual* (Hoekstra *et al.*, 2011). The combined metrics from these two methodologies provide an understanding of the pressure exerted by the livestock production sector on water resources worldwide with the aim of supporting a potential improvement in the sector's water productivity as well as a reduction in its contribution to water scarcity.

Water use efficiency vs water productivity

- **Water use efficiency** *refers to percentage of water effectively used by the plant (e.g. if a crop receives 10 mm of irrigation water, of which 8 mm are utilized through root water uptake and 2 mm are lost through drainage below the root zone or via unproductive soil evaporation, water use efficiency is 80 percent). The numerator and the denominator have the same units.*
- **Water productivity** *refers to the ratio of the benefit accrued to the amount of water consumed to produce those benefits (e.g. for wheat production, water productivity could be 50 kg of grain per 1 m³ of water). Water productivity is the metric used in this document.*

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. Herein, the term “shall” is used to indicate what is required for an assessment to conform to these guidelines; “should” indicates a recommendation, but not a requirement; “may” indicates 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, two types of water use assessment are considered in two chapters:

- **Chapter 5, Assessment: Water scarcity impact** – 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.
- **Chapter 6, Assessment: Water productivity** – the assessment of the water productivity of the system (e.g. for performance tracking purposes), following the methods of Molden (1997), Molden *et al*. (1998), Molden and Sakthivadivel (1999), Descheemaker, Amede and Haileselassie (2010), and Prochnow *et al*. (2012), and according to the *Water footprint assessment manual* (Hoekstra *et al*., 2011).
- **Chapter 4, Water use 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 (FAO, 2018a). No guidance has to date been provided by LEAP on (eco-) toxic impacts. An assessment following this document therefore has limited scope compared with a comprehensive water footprint (as per ISO 14046) and this should be acknowledged by the stakeholders. LEAP works closely with the Sustainable Development Goals (SDGs) and aims to accelerate the agenda through to 2030. Target 6.4 of SDG6 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.

As such, one of the goals of these recommendations is to address water scarcity through the assessment of the water productivity and water scarcity impact of livestock production systems and supply chains. The existence of the newly developed SDG Indicator 6.4.2 – Water stress is acknowledged, although it is currently defined in terms of "water withdrawal" and not "water consumption" (UN, 2018).

This document does not provide support for the assessment of comprehensive environmental performance, and does not regard the social or economic aspects of livestock supply chains (animal productivity and welfare). Considering that water footprinting is an evolving science, it is expected that the guidelines be continually revised based on reliable data and sound methodologies.

Application

Some flexibility in methodology is desirable in order to accommodate the range of possible goals and special conditions arising at different levels within the livestock sector, while at the same time providing guidance to achieve 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 adapted to assessing water-related environmental performance; on the other hand, the water productivity assessment is adapted to assessing efficiency. However, it is vital not to make misguided decisions or convey misleading information. Therefore, in situations where the overall water productivity metric of a production system incorporates indirect water use (e.g. from feed produced at different locations), it shall be accompanied by the water productivity metrics of direct water flows for each separate stage of the system, as well as by the water scarcity footprint of the analysed system, in order to satisfy the recommendations of these guidelines.

Use of the water productivity metric

The 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 by the water scarcity footprint of the analysed system.

To avoid potential confusion arising from the use of terms having different definitions outside this document, refer to the terminology in 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 transpires or evaporates.
Blue water	Freshwater flows originating from run-off 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 ISO 14046: 3.3.2 – ISO, 2014). Water inputs refer to 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 benefits gained to the amount of water consumed to produce those benefits in a production process (product units per m^3 water).

Blue and green water

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

1.2.2 *Objective of the guidelines*

The Water TAG was mandated to develop guidelines to support management solutions through improvement over time via a comparison of practices in livestock supply chains. It sought to make sound recommendations on water use assessment that adequately capture the specificities of livestock production systems. Building on existing standards and methods, the Water TAG aimed to reach a global consensus on the general topic of water footprinting of livestock supply chains. The specific 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. Animal health and welfare, although not assessed in this document, should be an overarching objective: water use should be optimized without any negative influence on animal welfare.

This assessment examines different metrics providing guidance on a range of water-related issues, and thus opens the door to a broad set of solutions. The most demanding step is the water use inventory. The inventory collects the information required to quantify the potential environmental impacts (on humans and ecosystems) and to measure the efficiency of water use in the system via the water productivity metric; the data are obtained from all interactions in the livestock production system involving water resources and its cycle. Following interpretation of the assessment results, it is possible to minimize potential environmental impacts while optimizing water use productivity.

The guidelines are structured in two parts subdivided into eight chapters. Part 1 (Overview and general principles) introduces the document, presenting the process of guidelines and environmental impact categories addressed. Part 2 (Chapters 2–8) presents the methodology:

- **Chapter 2, Scope –** provides information on the elaboration of the scope of the water use study itself.
- **Chapter 3, Data quality – data sources, databases –** describes data types, data quality and resulting uncertainties; the reader is referred to other documents and guidance is provided for handling missing information.
- **Chapter 4, Water use inventory –** lists methods for addressing the water use inventory, presents system boundaries and describes relevant water flows.
- **Chapters 5 and 6, Assessment –** describe and recommend two water scarcity impact assessment methods followed by water productivity metrics.
- **Chapter 7, Interpretation of results –** describes how the results can be interpreted to identify at which points in the production chain the process can be improved such that impacts are minimized and resource use efficiency is improved.
- **Chapter 8, 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 water scarcity impact assessment is designed to evaluate the contribution of an activity (e.g. livestock production) to water scarcity and the related potential environmental impacts of depriving other human or ecosystem water users. As scarcity is an issue with wide spatial and temporal variability, these aspects need to be quantified. Note that potential impact is not measured merely by volume: it must be placed in the context of local water scarcity and a characterization factor used to quantify it (section 5.4). Assessing the different contributions of a system's water consumption over the entire supply chain allows to identify the most impacting life cycle stages (from-cradle-to-gate) and hence to seek a solution with the greatest benefit for the environment.

Not only does a water scarcity impact assessment allow to understand the magnitude and distribution of potential environmental impacts associated with water scarcity, it provides a water scarcity footprint (ISO 14046 – ISO, 2014), which can be used in environmental impact reduction, communication and stakeholder engagement, water management and stewardship, sustainability strategy, and marketing of more sustainable solutions (Table 2).

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 be measured either as physical agricultural outputs or as the economic value of those outputs.

Table 2: Possible goals of water scarcity impact assessment such as water scarcity footprint

General objectives	Specific objectives (examples)
Resources efficiency and environmental impact reduction	Achieve product development and optimization including environmental criteria Establish organizational target to reduce direct and/or indirect water footprint Identify hotspots in terms of water footprint throughout the life cycle of a product or organization to prioritize investments
Communication and stakeholder engagement	Manage the license to operate of an existing production site Engage with local authorities to contribute to a watershed management plan Communicate to investors an organization's pressure on water
Water management and stewardship	Carry out risk assessment and management at site or organizational level Contribute to reduction of and compensation for the environmental impact of a product or organization
Sustainability strategy	Establish water reduction target and priorities 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	Provide marketing support for more sustainable solutions, focusing on aspects of water Use information for business-related activities and information for different markets

Source: Vionnet *et al*. (2017).

The amount of water consumed is defined as water removed from, but not returned to, the same drainage basin. Water consumption can be the result of evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea. An analysis of existing studies assessing water productivity of livestock production (Drastig *et al*., forthcoming) reveals important differences between different methods. The two main differences are "treatment of green water" and "including or excluding background processes as water input", to be seen in direct relation to the farm boundary versus the whole supply chain boundary. Other differences in the water consumption of livestock arise with regard to, *inter alia*, purchased feed, fertilizers, pesticides, antibiotics and the building of barns. Green water shall be included in the calculation of water productivity because it is particularly relevant for agricultural products. The increased productivity of green water use is important for meeting the rising global demand for food. In fact, a more productive use of green water implies a reduced need for additional blue water resources in the form of irrigation (Ran *et al*., 2016). The water consumption associated with pre-chains and capital goods (e.g. purchased feed and fertilizer, and production of equipment, machinery, buildings, facilities and vehicles) shall be included. The water productivity assessment aims to assist farmers to optimize the water flows in their farms and enhance water use through agronomic measures and farm management (Table 3).

A distinction is made between 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 the direct WP of a product as a means to track the performance of the system's foreground.
- Indirect + direct water productivity ($WP_{direct+indirect}$) also includes 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 the $WP_{direct+indirect}$ metric is to quantify water use in the assessed production system by considering direct and indirect water consumption per functional unit of product. However, as this metric does not inform on potential issues associated with the different water uses – since they 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 analysed system, in order to prevent misguided decisions based on $WP_{direct+indirect}$ and which may not represent an environmental improvement (e.g. if a higher productivity is associated with a higher water scarcity footprint). A combination of the $WP_{direct+indirect}$ metric and WSF may show potential to improve the overall performance of the system related to water consumption.

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.

Table 3: Goals of the water productivity assessment and associated method

Goal	Scale	User	Method
Assess energy conversion, biomass or harvestable yield from a particular feed crop or cultivar.	Crop	Plant physiologists, farmers	WP_{direct}
Assess energy conversion, biomass or harvestable yield from a particular feed cropping system.	Field	Soil and crop scientists, farmers	WP_{direct}
Assess yield or economic return from a farm's livestock production to assist farmers to understand the water flows in their farms and to optimize water use by agronomic measures and farm management at one specific farm location.	Farm	Farmers, agricultural advisers, processing industry, water managers	WP_{direct}
Assess yield or economic return from a farm's livestock production to assist farmers to understand the water flows in their farms and the resulting effects of optimizing water use through agronomic measures and farm management at the specific farm location and in potentially different regions.	Farm	Farmers, agricultural advisers, processing industry, water managers	$WP_{direct+indirect}$ (+ WSF, + WP_{direct})
Compare different livestock production systems to identify potential 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 managers	WP_{direct} or $WP_{direct+indirect}$ (+ WSF, + WP_{direct})

Source: Ran *et al.* (2016) (adapted); Giordano *et al.* (2017).

Production systems vary greatly in terms of practices, scale and degree of specialization, and they are found in a wide range of agroclimatic settings. A 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 imperative for the development of improvement strategies. Feed represents a major component of almost all livestock supply chains (section 4.3). Correspondingly, feed production often accounts for the largest segment of water use in livestock production and is the principal contributor to environmental impacts related to water scarcity. Hence, identifying the origin, type and quantity of feedstuff used for livestock feeding and determining the water use associated with feed production is of paramount importance in livestock water use assessments.

Many farms present a mixture of animal species (e.g. sheep, cattle, buffalo, poultry and swine), often farmed together. As far as possible, it is recommended to separate farm activities for the different animal species where specific practices can be defined (e.g. use of summer forage crops for beef and dairy cattle; feeding in confinement for a portion of the year; confined vs free range swine production). To estimate water use, the volume and nature of the water used for each livestock species shall be determined. This includes summing the various water consumption uses (section 2.8) for each of the livestock species in a mixed production system. For grazing (and non-grazing) livestock, water consumption shall be estimated based on the total feed intake for each of the different animal species and allocation shall be 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 (e.g. groundwater pumping or gravel and sand mining for concrete production) 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:

- cradle-to farm gate;
- cradle-to-processing gate; and
- cradle-to-final use.

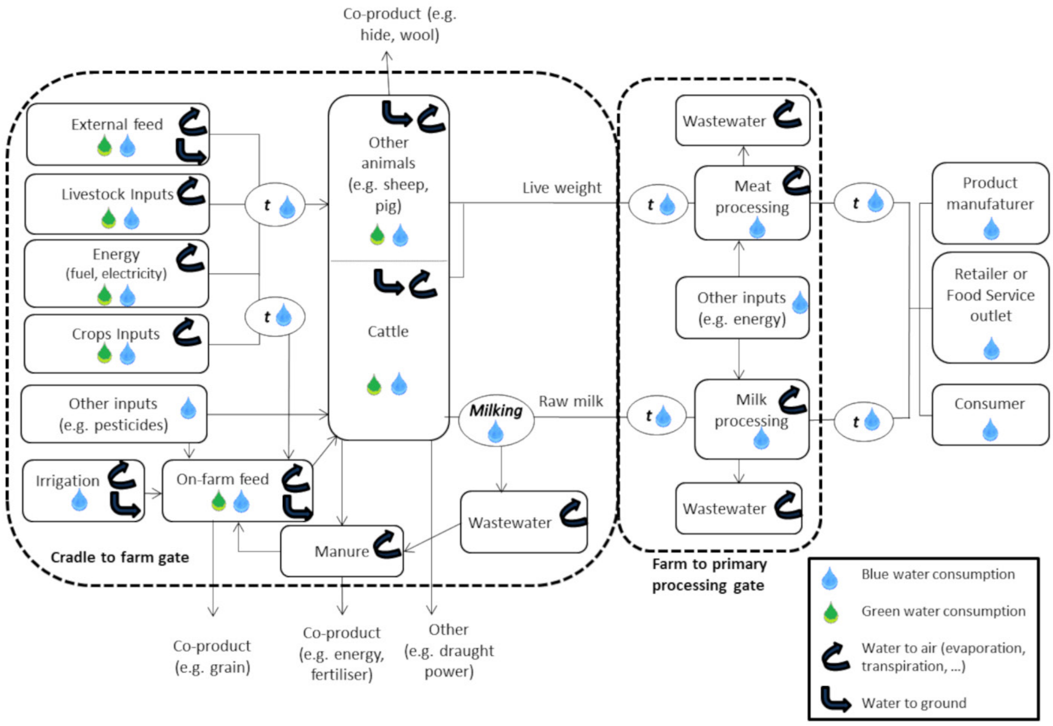
Figure 1 depicts a typical livestock life cycle including feedstock and livestock production, but also all phases supporting livestock activities, such as the production of inputs (e.g. pesticides, herbicides, fertilizer, energy and seeds) and co-products. In feedstock production, green water is involved at field level (in pastures and feed crops), while blue water is involved in the feed processing stage (to produce roughages, grains and concentrates). In livestock production, blue water is involved as drinking and service water (e.g. for cleaning) and during the primary processing stage as service/processing water and water used to produce other inputs (e.g. hydroelectricity). 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; these must be accounted for in the water use inventory as consumption or returned flows, depending on the context.

The overall system boundary covered by by the LEAP feed and animal guidelines (FAO, 2016d, 2016a, 2016b, 2016c, 2018b) represents the cradle-to-primary processing stages (e.g. processed milk) of the life cycle of the main products from livestock. It covers the main stages of cradle-to-farm gate, as well as transportation of animals to primary processing facilities and then to the primary processing gate (e.g. the output loading dock). Section 7.2 of each specific LEAP feed and animal guidelines depicts the modular approach followed: the production system is divided into modules that relate to different life cycle stages. The main stages can be summarized as 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 feed guidelines and encompasses feed production from the cradle to the 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 specific LEAP animal guidelines (section 11.2).

2.4 FUNCTIONAL UNITS AND REFERENCE FLOWS

The system of interest is water use in livestock production and supply chains. The concepts of functional unit (FU) and reference flow (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. provision of 1 000 litres 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, 2006a), such as 1 000 litres of bulk milk. Both functional units and reference flows shall be clearly defined and measurable.

Figure 1
System boundary and main water flows
of livestock production systems: cradle-to-processing gate



Note: t = transport.

In livestock production systems, FU and RF are specific to each species and differ depending on 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 the abattoir gate). Dressed weight is the final weight of the animal once the internal organs, head and inedible parts (tail, legs, skin, feathers etc.) have been removed. LEAP animal guidelines detail the FU and RF for each specific livestock species, especially when the final product could be different from meat. Table 1 in the LEAP guidelines on pig supply chains (FAO, 2018b) provides recommendations for the choice of FUs/RFs; Table 2 in the LEAP guidelines for large ruminants (FAO, 2016a) illustrates the recommended FUs/RFs for the three main product types from large ruminants (meat, milk, draught power) according to whether the product is leaving the farm or primary product processing gate; Table 1 in the LEAP guidelines on poultry (FAO, 2016b) reports the recommended FUs/RFs for different main product types of the sector (meat and egg); Table 1 in the LEAP guidelines on small ruminants (FAO, 2016c) illustrates the recommended FUs/RFs for the three different main product types from small ruminants (meat, milk, fibre) according to whether the product is leaving the farm or primary product processing gate. Commonly used functional units and reference flows of different livestock product systems are listed in Appendix 1; commonly used models are listed in Appendix 2.

2.5 CO-PRODUCT ALLOCATION

The ISO 14044 and ISO 14046 standards provide the following guidelines about handling multifunctional production:

- **Step 1.** Wherever possible, allocation should be avoided by:
  - dividing the unit process to be allocated into two or more subprocesses and collecting the input and output data related to these subprocesses; or
  - 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).

It is recommended to consult other LEAP guidelines (FAO, 2016a, 2016b, 2016c, 2016d, 2018b) regarding the assessment of the environmental performance of livestock species (pigs, poultry, small ruminants, large ruminants) to obtain details about species-specific recommendations on multifunctional processes and allocation. Allocation choices can be especially important for food “waste” fed to animals, since they affect how the food is allocated between the original purpose (e.g. human nutrition) and the feed.

2.6 GEOGRAPHICAL AND SPATIAL COVERAGE AND DISTRIBUTION OF THE STUDY

Fresh water is an increasingly scarce resource with widely varying availability on both a temporal and a spatial scale. The temporal and spatial scales of the study must be addressed according to the scope of the analysis. The 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 detail, and the scales, methods and potential applications of a water productivity assessment. The temporal and spatial resolution for water scarcity footprint is likely to depend on the impact method used; however, both methods presented in this document (section 5.4) recommend a monthly and watershed scale. When this level of resolution is not available (e.g. for background data), larger aggregation (e.g. annual and country scale) may be applied if supported by the impact method. The result of a water scarcity footprint 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 (~100–1 000 km^2), while for a water productivity assessment it may be as small as the field (< 0.5 km^2). In the latter case, water use per farm must be accounted for. Where there are big differences in water use across seasons or months, this should be taken into account.

2.7 TEMPORAL RESOLUTION

2.7.1 *Water availability*

Water availability fluctuates within and across years, resulting in variations in water demand over time. When undertaking a water use assessment, the period relating to the data used must be specified, since it will affect the outcome. Therefore, it is necessary to assess water use for a specific year (or period of several years) or to perform the assessment for a given climatic period – typically 30 years, or a minimum of 5 years (IPCC, 2001).

2.7.2 Feed production

According to the LEAP guidelines on animal and feed supply chains (FAO, 2016d), the feed production stage does not only have a physical boundary, but also a time boundary, and in section 8.4.2 the time boundary is defined by the length of the production cycle under examination. For multiple harvests of the same crop in one year, it may be decided to set the time boundary between two consecutive growing seasons. However, for a more detailed assessment, the time boundary may be set between two production cycles of the same crop, in which case the boundary is set when the crop or harvest 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 the previous crop or harvest (FAO, 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, because the land is permanently covered with the same type of vegetation. 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 LEAP guidelines on animal feeds supply chains (FAO, 2016d), section "Dealing with variability in crop production cycles" states 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 are provided for annual crops (3 years), perennial plants (steady situation and a 3-year rolling average) and crops grown and harvested in under 1 year (specific time for the production of a single crop from at least three recent consecutive cycles). The years selected should reflect as far as possible climate variability in the area.

2.7.3 *Animal production*

Section 8.4.4 of the LEAP animal guidelines defines the time frame for carrying out a study. A period of at least 12 months is recommended for all livestock species. In addition, the study shall use a herd population (in a steady state and with a population balance) representative of all animal classes and ages present over the 12-month period required to produce the given mass of product (FAO, 2016a, 2016b, 2016c, 2018b).

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 consumption data considered may be of more limited scope; nevertheless, the general recommendation is to assess both direct and indirect water consumption, since the indirect water consumption may be much greater 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 processes) – 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 (primary production and finishing); and
- services 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 – water used (consumed) to produce electricity, which is used all along the production chain at feed production (including production of fertilizers and pesticides), primary production, finishing and slaughtering stages; and
- water for production of fertilizers, pesticides etc.

3. Data quality – data sources, databases

3.1 GENERAL PRINCIPLES

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 on different scales ranging from individual farms, to integrated production systems, to regional, national or sector levels. When evaluating the data collection requirements for a project, the influence of the project scope must be taken into consideration. In general, these guidelines recommend the collection of primary data for foreground processes, which are generally considered to be under the control or direct influence of the study commissioner.

However, it is recognized that for assessments with a wider scope, such as sectoral analyses on a 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 stage 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 3–5 years).

When performing a water use assessment, it shall be demonstrated that the following **"water inventory principles"** are considered (adapted from ISO14044 – ISO, 2006a):

Representativeness – referring to a qualitative assessment of the degree to which the data reflect the true population of interest and covering the following dimensions:

- Temporal –_age of data and length of time over which data were collected.
- Spatial – geographical area from which data for unit processes were collected to satisfy the goal of the study.
- Technological – specific technology or technology mix.

Source, precision, completeness:

- Source – source of the data (e.g. reference or measurement).
- Precision – measure of the variability of the data values for each datum expressed (e.g. standard deviation).
- Completeness – percentage of data (e.g. of freshwater input) that is measured or estimated.

Consistency, reproducibility and uncertainty:
- Consistency – qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis.
- 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.
- Uncertainty – uncertainty of the information (e.g. data, models and assumptions).

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:
- **Primary data** are measured or collected directly and are representative of processes at a specific facility or of specific processes within the product supply chain. Primary data refer to information that is collected directly as part of the current study. The LEAP guidelines for the poultry sector (FAO, 2016b) include a data collection template in the Appendices.
- **Secondary data** refer to information obtained from sources other than direct measurement of the inputs/outputs from processes included in the life cycle of the product (BSI, 2011) available in existing life cycle inventory (LCI) databases or collected from published literature. Secondary data are used when primary data of higher quality are not available, or when it is impractical to obtain them. Water use for crops intended as feed for livestock is calculated using a model, and is therefore considered secondary data.

3.2.1 *Approaches for handling missing data*

Data gaps exist when there are no primary or secondary water use data available that are sufficiently representative of the given process in the product's life cycle. Gaps in LCI data can lead to inaccurate and erroneous results (Reap *et al*., 2008). Required data sets can be compiled using a two-step procedure:
- **Screening –** using readily available specific and/or generic data sets to identify the most sensitive and influential – but uncertain – data inputs, that is the "main data inputs".
- **Compilation –** striving 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 with recognized international reference data systems, such as the International Reference Life Cycle Data System (ILCD) (European Commission/Joint Research Centre/Institute for Environment and Sustainability, 2010).

3.2.2 *Data quality*

Practitioners shall assess data quality by using data quality indicators (i.e., the data quality criteria in Table 4). Generally, data quality assessment can indicate both the representativeness and the quality of the data. The assessment of data quality is important for improving the data content of the inventory, achieving proper communication and interpretation of the results, and 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 (ISO 14040 – ISO, 2006b). 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 data sources and data quality, as well as any efforts made to improve data quality.

3.2.3 *Guidance to assess primary data*

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

3.2.4 *Guidance to assess secondary data*

Secondary data refer to LCI 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:

- should be as current as possible and collected within the previous 5–7 years; if only older data are available, documentation of the data quality is required and the sensitivity of the study results to these data must be investigated, determined and reported;
- should be used only for processes in the background system; when available, sector-specific data shall be used instead of proxy LCI data;
- shall fulfill the data quality requirements specified in these guidelines; and
- 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 represent the process, proxy data shall be used.

3.2.5 *Data quality indicators*

An evaluation of the quality of these data sets 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 data uncertainty in the absence of reported uncertainty, which is often the case (section 3.3).

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 are crucial for the proper interpretation, reporting and communication of results.

Uncertainty in water use assessments could be introduced by two main factors:

- **parameter uncertainty** – uncertainty in data inputs; and
- **model uncertainty** – choice of the model including system boundaries, allocation choices, spatial and temporal representativeness and other assumptions.

Parameter uncertainty should be quantified by using appropriate statistical techniques; for example, the World Resources Institute (WRI) and World Business Coun-

Table 4: Overview of data quality criteria

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

cil for Sustainable Development (WBCSD) (WRI & WBCSD, 2011) published additional guidance on quantitative uncertainty assessment, including a spreadsheet to assist in the calculations. Model uncertainty should be assessed using a scenario analysis. Uncertainty can be assessed in 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; and
- **numerically** – e.g. by Monte Carlo simulation, a well-known form of random sampling used for uncertainty analysis and 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 water-related environmental performance in certain regions or even at field level to certain reference levels and to formulate improvement targets aimed at decreasing 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 (at both inventory and water scarcity impact assessment level) requires accurate quantification of both water use data in the production process and local hydrological data regarding 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 the models used. Water use and hydrological information are generally estimated/modelled for regional and global 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 on higher spatial and temporal scales. This creates 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

Table 5: Tiered approaches of uncertainty assessment

Tier level	Spatial scale	Temporal scale	Data sources/methods
Tier 1	Global level Regional level (agroclimatic zones)	Annual or monthly average	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

tiered approach is suggested (Table 5 and Table A9.1) to match the scale of analysis and the data availability/sources with the analysis conducted (Hoekstra *et al*., 2011). The application of Tier-2- and Tier-3-level approaches will provide more accurate estimates and a sound knowledge base, but at a cost of greater effort and more resources.

3.3.4 *Data proxies*

When data gaps exist and proxies are used – chosen from the ranked options listed below – this shall be recorded in the study report. If proxy data are used, their impact on the uncertainty of the model shall be determined and discussed in the study. The user can identify proxies from the following options:

Country of origin known:

1. Use the same ingredient from another country with similar blue water availability and climate zones.
2. Use a similar crop (in terms of water demand and growth period) from the same country conditions.
3. Use a product group average from the same country (e.g. if data are missing for sorghum from Argentina, another cereal with a similar water requirement in Argentina can be used as proxy).

Country of origin not known:

1. Use the regional or world average (e.g. production-weighted arithmetic mean).
2. Use the product group average (if the regional/world average is not available).

4. Water use 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 species, breed, age, growth rate, pregnancy, production status, activity, feed type and weather. Water requirement and intake are also strongly affected by climatic factors, particularly environmental temperature. Up-to-date steps to calculate the water requirements of livestock species (taking into account physiological status and environmental conditions) can be obtained from standard scientific guidelines detailing the nutrient requirements of a given species. For example, the most up-to-date equations to determine the drinking water requirement of various classes of beef cattle are presented in a document released recently by the National Academies of Sciences, Engineering, and Medicine (2016).

As with any inventory exercise, the steps involved are: data collection (using the principles outlined in Chapter 3); recording and validation of data; relating of 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 comply with ISO 14046 standards.

4.2 PRODUCTION SYSTEMS

Large ruminants. Cattle and buffalo are the main economically important large ruminants in the world; in 2014, they totalled, respectively, about 1.5 billion and 195 million heads. Large ruminants are raised in a wide variety of agro-ecological zones with varied climatic, soil and topographic conditions that determine the quantity, quality and composition of the livestock feeds – and thereby the productivity. Cattle and buffalo play valuable multifunctional roles. A detailed classification of large ruminant production systems and a description of the supply chains of beef and dairy cattle are provided in the FAO-LEAP document, *Environmental performance of large ruminant supply chains: Guidelines for assessment* (FAO, 2016a).

Small ruminants. Globally, there were 1.2 billion sheep and 1 billion goats in 2014. About 83 percent of the world's small ruminants are found in Africa and Asia. Sheep and goats have valuable multifunctional 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 presented in the FAO-LEAP document, *Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment* (FAO, 2016b).

Pigs. The world pig population in 2014 was about 987 million, of which Asia accounted for 60 percent. Several pig production systems can be identified in a given country or region, from the simplest systems requiring a small amount of investment (e.g. backyard production systems) to large-scale commercial pig farms.

A description of common pig production systems and supply chains is provided in the FAO-LEAP document, *Environmental performance of pig supply chains: Guidelines for assessment (Version 1)* (FAO, 2018b).

Poultry. The global poultry population in 2010 was estimated at almost 22 billion birds, nearly three times as many as in 1980, with chickens (including nearly 6 billion laying hens) making up 90 percent of the total. Poultry production systems may be classified based on production scale, housing, feeding system, genotype and health provision. Additional details about poultry production systems and supply chains are available in the FAO-LEAP document, *Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment* (FAO, 2016c).

4.3 DEFINING FEEDS OR FEEDING STUFF

Feed is defined as any single or multiple materials – whether processed, semi-processed or raw – intended for feeding directly to animals (FAO/WHO, 2008). Livestock feeds provide the basic nutrients required for animal production, including proteins, amino acids, minerals, vitamins and other micronutrients. The animal diet 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, millet), oilseed crops, feed produced as by-products (e.g. cottonseed cake), forages (e.g. grasses, legumes, silages), distillers' grains, crop residues, grain screenings or grains

Water use assessment on farm scale

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

General areas of focus for conducting a farm-scale assessment:

- *On-farm feed production and purchased feed (e.g. rain-fed systems, irrigated systems, pasture 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.*
- *Water used and consumed for cleaning, cooling and farm administration.*
- *Livestock water balance, taking into account flows of water within the animal (water ingested during feeding and drinking, including metabolic water production), losses through respiration and perspiration, incorporation of water in the product, and water excretion in urine and manure.*

In addition, data shall be collected regarding livestock numbers and live weight production. In order to predict drinking water, an integrated assessment of production, feed intake and water intake is required to ensure consistency.

excluded from the human food chain. 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. A broad distinction can be made between ruminant and monogastric species: ruminants are largely dependent on feed materials from crop production, such as grains (cereal and legume crops), oilseed crops (canola, cotton, soybean etc.) and household waste; monogastric species depend on roughages, such as grasses, plant leaves and forage feedstuffs.

4.4 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 (i.e. input and output) crossing the system boundary. In accordance with ISO 14046 (ISO, 2014), the elementary flows are listed and details are provided on: quantity of water used; resource type (precipitation, surface water, seawater etc.); type of usage (evaporation, transpiration, incorporation, return, consumption etc.); and temporal and geographical aspects. Typically, the results of a water balance are reported relative to the appropriate reference flow for a particular process – for example, per tonnes 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 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 subsections 4.4.2, 4.4.3 and 4.5.3.

As a result of biological, geological and meteorological changes, as well as civil engineering projects, land use variations occurring during the life cycle of livestock may change the hydrological flows of both surface water and groundwater. Changes in land use may affect the partitioning of precipitation between surface run-off, percolation and evapotranspiration, with consequences for water consumption. Specific notes on the issue of land use are available in section 5.8, "Working towards impact assessment of green water consumption".

This section applies to feed ingredients of plant origin, all of which 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 run-off, 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 they 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 recirculation within the feed system boundary. Water associated with urine and manure may evaporate from the system, representing an output of the water balance and a consumptive use. Evaporative losses from irrigation supply systems should also be treated as water consumption (Emmenegger *et al*., 2011).

Allocation of grain crop residue grazing by livestock

Grain and forage may be contained in the same plant – for example, with cereal grains, both the grain and the straw may serve as livestock feed. In such cases, green and blue water use should be assigned to the feeds as per the principles of allocation described in section 2.5. If the straw is not used as feed, all water use should be assigned to the production of feed grain. Water use associated with the straw should 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 floodwater would be considered blue water and, consequently, water consumption by grass or crops using the residual soil water would be considered blue water consumption. However, the water retained in the vadose (unsaturated) zone could not be directed to alternative uses (as is the case with green water). This is dealt with at the water scarcity impact assessment stage. In general, neither green nor blue water consumption are measured in feed production, because evapotranspiration typically cannot be measured, especially for large areas. Therefore, green and blue water consumption are commonly estimated by measuring other components of the water balance or through modelling. One example for a data source specifically for Africa and Near East is the FAO WaPOR tool (http://www.fao.org/in-action/remote-sensing-for-water-productivity/database/database-content/en/). In stables, water meters located on the farm can be used to measure blue water use; however, meters may provide little information on water consumption.

Blue water 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 depending on 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-percent inclusion rate of cottonseed from irrigated cotton production fed in the ration of beef cattle was found to contribute 25–36 percent 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 be taken into account. If no primary data are available, care is required to ensure that the proportion of farms using irrigation, and the amount of water used, is representative of the regional or national system being investigated. Small differences in irrigation can have very large impacts on freshwater consumption for livestock. In regions with variable water availability, 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 almost twofold between low and high water availability during the year (Wiedemann, McGahan and Murphy, 2017). The water use inventory shall be crop specific, including geographic location of the watersheds (when available) or country of origin. With regard to water scarcity, it is preferable to avoid making averages over diverse geographies specifically, as they would result in different impact assessment values. For this reason, if two different regions export the same feed component, a separate figure should be specified for each region (ideally using a weighted average by the relative import volume between them).

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 that accurate and representative data sets are used to determine water consumption. These data sets may require specific attention to ensure water flows are accurate and complete.

4.4.2 *Calculation of crop water consumption*

Crop water consumption (Q_{ET}, mm) for determining 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):

$$Q_{ET} = \sum (ET_c \times K_5) = \sum (ET_o \times K_c \times K_5)$$

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

K_c is the crop coefficient under optimal agronomic conditions; it 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 the values provided by Allen *et al.* (1998) can be used. To be able to distinguish between productive and non-productive water consumption, 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 depends 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 the 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 the sake of transparency. In addition to crop water consumption, eventual evaporation from artificial storage reservoirs and irrigation canals needs to be added.

In cases where the crop is irrigated, Q_{ET} must be partitioned between blue water ($Q_{blue,ET}$) 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 is consumed by the crop; some is returned via drainage and run-off and this is rarely measured. Therefore, the consumed fraction must be estimated from local studies or literature – a crude approach subject to major 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.

Feed crops and pasture and grasslands

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 the fraction of pasture biomass actually consumed by animals (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; on the other hand, only a fraction of the land's received green water is included in 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 grasslands

The water use inventory (Q_{feed}) in rain-fed pasture and grasslands consists of the green water inventory $Q_{green,feed}$. To estimate the rain-fed pasture intake (tonnes) relevant for productivity assessment only, it is necessary to calculate the mass of feed eaten by the livestock. FAO (2016d) provides guidelines on how to estimate the amount of feed consumed by animals. Two methods are presented here:

- To estimate the intake per animal per day, fence off part of the grazed field. After the grass is harvested, divide its DM weight by the number of animals grazing and the number of days the area was fenced off (site-specific, short-term estimates).

- To calculate the energy demand of the grazing animals, use an energy model (e.g. https://cgspace.cgiar.org/handle/10568/4675). Subtract from the energy requirements of the animal the energy fed as hay, silage or cereal concentrates (this requires a measurement of the feed consumed and its energy content). It is assumed that the energy deficit is 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 (tonnes) and yield (tonnes/ha) reported by 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 grasslands of a farm following the procedure of the water use inventory (Q_{feed}) calculation for rain-fed feed crop production.

Irrigated pastures

The 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 by the livestock and that eaten by the livestock; the latter is used in the assessment. It takes into account rations (tonnes) and yield (tonnes/ha), either reported by the farmer or extracted from statistical data on yields of irrigated feed and the animals' requirement of irrigated feed. 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 crops

Rice bran is a commonly used feed crop for livestock, including pigs and poultry, and – in China –large ruminants. The water inventory in flood or deepwater feed crops (e.g. rice) comprises green water consumption and blue water consumption. For example, in paddy rice fields, evaporation from open water bodies is much higher than transpiration through the plants. 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; percolation, on the other hand, is not a loss to the catchment (Chapagain and Yamaji, 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 *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 taking into account fluctuations in yearly averages. If such data are not available, 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 a background process when feed is not grown on farm. Water can be associated with inputs necessary to grow crops (e.g. electricity, fertilizers, pesticides and fuel) 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 these 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 a cooling agent or as an input (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.

4.5 ANIMAL PRODUCTION

4.5.1 *Diet composition and feed intake*

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

Diet composition differs substantially both across livestock species and within different systems and different production cycle stages of the same livestock species. Diets fed in confinement are often complex, comprising several ingredients designed to meet the nutrient requirements for optimizing meat, milk or egg production. These ingredients may be sourced locally or imported over vast distances. Other diets may be less complex, consisting of a single ingredient (e.g. grass hay used to maintain beef cattle). The exact composition of the diet may sometimes be difficult to determine, for example, with 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 in various ways. In a limited number of situations, measured data can be used to define the on-farm feed intake required to produce animal products. This is only likely to apply in situations where livestock and poultry are housed in confinement with known amounts of feed delivered daily. In other cases, livestock and poultry may obtain feed partially or totally under free-range conditions where it may not be possible to have an accurate measurement of the total quantity of feed consumed.

In such cases, the total feed intake is calculated based on 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, wastage of feed occurs at the various stages between harvest and feeding and this shall also be accounted for. For example, if there is 10-percent wastage between the harvesting of maize and its 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 amount of feed wastage occurs during feeding and this loss should also be accounted for (FAO, 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 and eggs). A simplified population example for a dairy farm is provided in Appendix 5 (Figure A5.1).

According to the LEAP animal guidelines (FAO, 2016a, 2016c), when estimating livestock populations it is necessary to account for the number of breeding females and males within the animal population as well as those used as replacements. The number of animals removed from the population – whether for use as meat or because 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 taking into account the various factors potentially influencing 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 based on the number of adult breeding animals, population replacement rate and fertility, and following the LEAP animal guidelines (FAO, 2016a, 2016c).

In general, annual average population is sufficient for most livestock. However, estimation of the yearly population of some species (e.g. broilers) can prove challenging with several production cycles in one year. In such cases and where possible, regional information on the production system shall be used.

Population data may need to be extended to include livestock transferred between farms. Furthermore, the extent of water use, availability and impact may differ dramatically between production locations. In such cases, 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 analyses at national or regional level, 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 is necessary to use regional data for the specific contributing farm(s) considered based on the system boundary of the study in question.

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. This information is critical when the functional unit is established as a unit of a given product (e.g. litres [milk] or kg [meat]) and 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 (relative to a dairy farm). This type of balance can help in selecting the flows that stay inside the system balance (e.g. soil water storage) and those that enter and exit the system boundary and must be taken into account.

Figure 2
Physical flows of water at dairy farm level

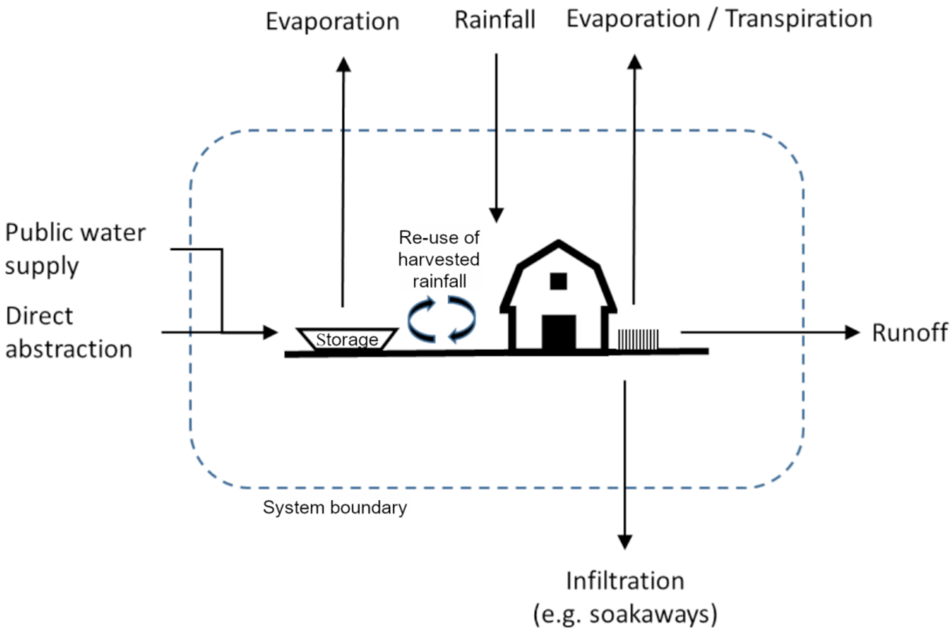
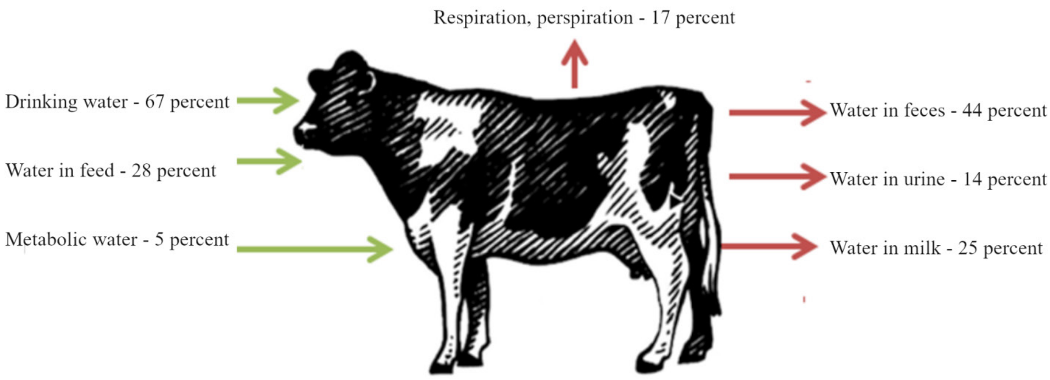


Figure 3
Water balance in a lactating Holstein dairy cow (%)



Source: Khelil-Arfa *et al.* (2012).
Note: Percentage figures should not be used as a default reference, since water flows depend on specific milk yield, dry matter intake, body weight and diet dry matter content.

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 and 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 is mainly from blue water sources, whereas water ingested in feed and metabolic water (which also arises from feed) 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.

Livestock production systems differ in terms of quantity of water used per animal and how the 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 (Figure 3; section 11.3.2 in the LEAP guidelines on environmental performance of pig supply chains [FAO, 2018b]). 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, Nguyen and Viljoen, 2010).

Examples of typical ranges of drinking water demand for livestock and poultry are provided in Appendix 4.

Poultry

Water requirements in poultry are strongly related to feed consumption and air temperature. Once air temperatures exceed 30 °C the expected drinking water intake can increase by 50 percent above normal rates (OMAFRA, 2015) (Table A4.1). Increasing protein and salt concentration in the diet leads to an increase in drinking water intake. There is a clear relationship between drinking water intake and protein content, protein quality (balance of amino acids) and uptake of electrolytes.

Swine

Maturity and weight associated with diet, temperature, housing and feeding methods have a major influence on swine water requirements. Any increase in protein and salt concentration in the diet increases the drinking water intake (NDSU, 2015) (Table A3.3; Table A4.2).

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, results in increased drinking water intake (OMAFRA, 2015) (Table A4.3).

Large ruminants

Cattle

For drinking water demand for beef production, refer to Table A4.4.

Dairy herds

Water constitutes 87 percent of milk and this figure can be considered a standard (USDA, 2016); approximately 30 percent of water ingested by dairy cattle is incorporated in their milk (NDSU, 2015). Thus, the water requirements of dairy cattle are strongly influenced by the production stage and the 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 of the feed and environmental factors such as air temperature and humidity. The cow's peak water intake is generally during the hours of greatest feed intake (OMAFRA, 2015) (Table A4.5).

4.5.4 *Housing water balances*

A range of services require water use in order to maintain the animals' environment; such services include cleaning the animal housing and yards, washing the animals, cleaning the milking parlour, and cooling, depending on the species and housing type. Intensive production has additional service water requirements for cooling and cleaning facilities, generally resulting in much higher overall water consumption compared with extensive systems. However, water use in intensive systems tends to be far more efficient per kilogram of product. Washing and leakages can significantly affect water use: water for farm washing is estimated to account for 20 percent of the blue water used (although mostly not consumed) for dairy cows (Thompson *et al*., 2007); leakages represent almost 5 percent of blue water use.

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 waste water management system. Evaporation is a consumptive loss. Water supplies originating from constructed reservoirs may also have an associated consumptive loss from evaporation.

In many cases, farm water use is not metered and even when it is, it is not usually possible to isolate water used for livestock housing from general farm water use; consumptive water is even more difficult to isolate. Algorithms for the calculation of water flows in animal production can be used (e.g. National Academies of Sciences, Engineering, and Medicine, 2016; Holter and Urban, 1992; Meyer *et al*., 2004; Cardot, Le Roux and Jurjanz, 2008; Krauß *et al*., 2016).

4.5.5 *Waste water management system balances*

Water associated with manure and urine also represents flows, and the final use of this water depends 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 overestimated. Where manure remains in a managed manure system, the inputs to the waste water management system are the outputs 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 waste water 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 be considerably changed with potentially significant impacts on receiving water bodies. Pollutants from improperly disposed animal waste may also be washed into storm sewers by rainwater. Storm sewers usually drain directly into water bodies (lakes and streams), carrying many pollutants with the water. Potential impacts associated with these pollutants should be assessed according to water quality impact categories including eutrophication and acidification (FAO, 2018a) and (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 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 (FAO, 2016d).

4.6 ANIMAL PRODUCT PROCESSING

Processing of livestock products typically uses a small but 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 simple systems use water largely for cleaning and washing of products, while sophisticated processors use water in washing, chilling, scalding, cleaning and, in some instances, pasteurization. Even in large processors, water use can vary substantially due to the presence of water treatment facilities and the ability to recirculate 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 (Wiedemann *et al*., 2017; Wiedemann, McGahan and Murphy, 2017); as a result, the system boundary is often at the farm gate. Where boundaries lie beyond the farm gate, information on water use at the processor should be obtained. If this primary information is not available, default values can be used. A range of water use estimates for the processing of various meat sources is provided in Table A4.6.

4.6.1 *Transport, capital goods and energy carriers*

Transport 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 for sanitary reasons before and after transporting animals or animal products. Water consumption can also be associated with the production of the means of transport, as for other capital goods 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 (e.g. for the production of equipment, machinery, buildings, facilities and vehicles) shall be part of the water use inventory. The same applies for energy carriers (electricity, fuel). The recommendations of the LEAP feed guidelines (FAO, 2016d) shall be used to identify the water use inventory requirements for energy carriers.

Table 6: Data for computation of water balance

Main inventory item	Data	Types of recommended data	Examples of sources
Feed system water balances	• Transpiration or evapotranspiration of each feed component • Irrigation water demand • Feed demand (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 feed production (year of cultivation, origin region), plots (soil types), data on outputs (output of fields, harvest date, harvest date of previous crop, output water content, output name), information about plants (variety name, acreage, average yield) (secondary data). 3. Transpiration or evapotranspiration of each feed component with fallow period from peer-reviewed papers or technical reports (secondary data).	1. Actual evapotranspiration determined for lysimeters as the difference between the amounts of precipitation + irrigation and drainage water (Katerji and Mastrorilli, 2009). 2. Cropwat, Decision support tool (FAO, 2019a); WaPOR (FAO, 2019b). 3. Drastig *et al*., 2016; Ercin, Aldaya and Hoekstra, 2012; Flach *et al*., 2016; Lathuilliere *et al*., 2014.
Animal system water balances	Drinking water demand	1. Stable measurement of drinking water demand (primary data). Modelled drinking water demand. Required information: head of animals, live weight of animals, dry matter content of feed, mean daily ambient temperature, sodium intake, milk yield (dairy) (secondary data). 2. Drinking water demand from peer-reviewed papers or technical reports (secondary data).	1. Continuous monitoring of water intake of animals (Cardot, Le Roux and Jurjanz, 2008; Holter and Urban, 1992; Krauß *et al*., 2016; Meyer *et al*., 2004). 2. Palhares and Pezzopane 2015; Drastig *et al*., 2016.
Animal housing water balances	• Cooling water demand • Service water demand for: • surface cleaning - cleaning of milk tank (dairy) - cleaning of milking equipment (dairy) - udder cleaning (dairy)	1. Stable measurement of 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. Required information: surface areas, number of rinsing cycles, number of cleaning procedures, number of milking processes (dairy) (secondary data). 3. Water demand of animal housing from peer-reviewed papers or technical reports (secondary data).	1. Continuous monitoring of water demand for cooling and service (Krauß *et al*., 2016). 2. Drastig *et al*., 2016.

5. Assessment: Water scarcity impact

5.1 INTRODUCTION

Water scarcity impact assessment entails the appraisal of the potential environmental impacts associated with the amount of water consumption quantified in the water use inventory phase (ISO, 2006a and 2006b). The same amount of water consumption in different places does not produce the same environmental impact, because water availability and environmental vulnerability are not homogeneous throughout the world. Impact assessment provides additional information to interpret the potential contributions to the environmental impact of the target livestock during its life cycle.

There are several impact pathways leading to potential environmental impacts associated with water use, depending on whether the impacts 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 multiplying inventory results by characterization factors (which act as conversion factors from water inventories to impact category indicators).

The above steps are the required parts of a water scarcity impact assessment. Subsequent weighting and aggregation of different category indicators, if several are used, is optional and shall be done according to ISO 14046 (ISO, 2014).

5.2 SELECTION OF IMPACT CATEGORIES

The selection of relevant impact categories is key for obtaining results that correspond to the goal and scope of the assessment. In general, environmental issues related to water use are classified according to two attributes: **quantity** and **quality**. However, document is limited to the discussion of quantity aspects. For water quality assessment, it is possible to refer to other guidelines in line with ISO 14046 (ISO, 2014) and which cover eutrophication, acidification and (eco-)toxicity (e.g. *Guidelines for environmental quantification of nutrient flows and impact assessment in livestock supply chains* [FAO, 2017]), PEF recommendations [Technical Secretariat for the Red Meat Pilot, 2015; Technical Secretariat, 2015a, 2015b, 2016]) and the UNEP/SETAC Life Cycle Initiative [Sonnemann and Valdivia, 2007]).

With regard to **quantity** and the environmental impacts of water use, it is necessary to consider the sufficiency of water resources to meet local demand. In the water footprint ISO 14046 standard, water scarcity is defined as "the extent to which the demand for water compares to the replenishment of the area" (ISO, 2014). The water footprint assessment manual (Hoekstra *et al*., 2011) also discusses broader dimensions (environmental, social and economic impacts) of sustainability in water use.

The scopes of the impact categories defined in the ISO 14046 standard of water footprint (ISO, 2014) and the environmental dimension of the water footprint sustainability assessment (Hoekstra *et al*., 2011) are similar. However, there are differences: the latter focuses on the **quantification of the volumes of water** used in areas and periods designated as "unsustainable" (i.e. where human consumption and environmental flow requirements already exceed renewable availability); the former focuses on the **quantification of the potential impacts** on the environment. On the other hand, they both relate to **water scarcity**, as described below.

Water scarcity

Water consumption throughout the life cycle of livestock may lead to reduced availability of water in an area and may create damage to the environment. The severity of water resource deficit depends on the demand for water compared with its replenishment. When calculating the impact category "water scarcity" (ISO 14046 – ISO, 2014), a scarcity index is used and results in a category indicator that represents the potential impacts, via deprivation of water resources, on users in an area. In most cases, the index is continuous and allows for a description of a range of levels of scarcity (see "AWARE" in section 5.4); in some cases, a binary approach is adopted – the equivalent of using a value of 1 when demand is larger than availability and 0 when this is not the case (section 5.4).

5.3 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 towards the end-point damage; examples include human health and ecosystem quality. Category indicators may be chosen anywhere in an environmental mechanism, that is at any point along the impact pathway from human intervention (in this case, water consumption) to damage to the environment (ISO 14044 – ISO, 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.

The various methods available all present specificities; a method and should be clearly understood when applied. Details of the recommended methods and their intended goals are provided in section 5.4; in addition, a non-exhaustive list of other methods is in Appendix 6 (Table A6.1). This section of the guidelines examines the contribution to water scarcity of blue water only (for green water, see section 5.8).

Many different water consumption impact assessment models have been developed (Appendix 6). While some are based on similar concepts, they differ in the modelling (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 the impact assessment. A method comparison study (Boulay *et al*., 2015a) found some differences in models characterizing the same impact pathways, although most characterization factors were similar and consistent in rank. A case study of sensitivity analysis of model choices proved that impact assessment results differ depending on the choice of model (Boulay *et al*., 2015b). Therefore, selecting an appropriate impact assessment model is crucial in the impact assessment phase and shall always be in line with the assessment goals.

Various scarcity impact assessment methods and approaches exist to assess potential impacts associated with scarcity. Available WAter REmaining (AWARE) and Blue Water Scarcity Index (BWSI) – described below – are recommended for the following reasons:

- detailed resolution at which they are provided (monthly and watershed based);
- consideration of environmental water requirements; and
- level of support from their respective communities.

Nevertheless, the user may consult Appendix 6, the literature and most up-to-date reviews that describe, analyse or illustrate the application of other methods (Sala *et al.*, 2016. If an alternative method is chosen from Appendix 6 or the literature, deviation shall always be justified with reasoning.[1] In addition, the ISO document TR 14073 (ISO/TR, 2017) contains illustrated examples of the application of ISO 14046 using various methods. LEAP Water TAG recommends applying a minimum of two water scarcity impact assessment methods for best practice and as sensitivity analysis.

5.4 WATER SCARCITY IMPACT ASSESSMENT

Most of the scarcity indicators that exist, both within and outside life cycle assessment (LCA) practices, relate human (blue) water use (withdrawals or consumption) to local and renewable (blue) water availability. Several indicators also reserve part of the flow for aquatic ecosystems requirements. Given the way these parameters relate to each other, additional modelling aspects, scales, units and data sources result in a variety of scarcity indicators and interpretations. A clear 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.

Summary

- *Apply at least two methods: AWARE and BWSI (or an alternative method from Appendix 6 or the literature).*
- *Should an alternative method be chosen from Appendix 6 or the literature, justify the deviation with reasoning.*

AWARE and BWSI are recommended because they:

- *are provided at the detailed resolution (monthly and watershed based);*
- *consider environmental water requirements; and*
- *are well received in their respective communities.*

AWARE provides factors between 0.1 and 100 $m^3_{world\ eq.}/m^3$ consumed, while BWSI permits the identification of regions where BWSI > 1. Both methods assess water scarcity on a localized spatial scale on a monthly basis, and account for the flows required to remain in the river to sustain flow-dependent ecosystems and livelihoods. The result is an accurate picture of water scarcity highlighting the variability during the year – variability that might be underestimated when measured or averaged on a full basin scale and at an annual level (Mekonnen and Hoekstra, 2016). While both methods use the three parameters – human water consumption, water availability and environmental water requirement (EWR) – EWR is assessed differently. In AWARE, a monthly and regional fraction varying between 30 percent and

[1] Such as the assessment goal not being met by the methodology (e.g. if the goal is to focus on non-renewable [fossil] groundwater resources).

60 percent of available flow is used (based on Pastor *et al.*, 2014), whereas in BWSI, a constant 80 percent is used everywhere (based on Richter *et al.*, 2011). The two methods are described in further detail below.

AWARE

For the assessment of impact on water scarcity, the Available WAter REmaining (AWARE) model (Boulay *et al.*, 2018) was recommended by the UNEP/SETAC Life Cycle Initiative based on consensus building by international stakeholders (UNEP, SETAC and Life Cycle Initiative, 2017). AWARE captures the potential impacts of water consumption in a watershed by representing the amount of water remaining in the watershed after human water consumption and environmental water requirements have been deducted. Thus, AWARE assesses the potential to deprive another user (human or ecosystem) 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 using the AWARE model identify the quantitative difference of potential impacts of water consumption in a process of livestock production, and allow for comparison with a benchmark.

The characterization factor of AWARE expresses the relative amount of available water remaining per area in a watershed, compared with the world average, allowing the comparison of cubic metres consumed in different regions of the world, converting them to cubic metres world equivalent ($m^3_{world\ eq.}$). The local factor (provided by the method[2]) is multiplied by the corresponding local water consumption obtained in the water use inventory, and the result is expressed in $m^3_{world\ eq}$. The assessment can be performed on a monthly or annual scale.

According to Boulay *et al.* (2018), the factor is calculated as follows (and provided online per watershed and country):

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

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

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

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

where demand refers to the sum of human water consumption (HWC) and environmental water requirement (EWR), and availability refers to the actual run-off (including human impacts – flow regulation and water use), all calculated in m^3/month, while area is calculated in m^2. *AMD* refers to Availability minus Demand. 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 is calculated 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 characterization factor (CF) are dimensionless, expressed in $m^3_{world\ eq.}/m^3_i$ (Eq. 3) (Boulay *et al.*, 2018).

[2] www.wulca-waterlca.org

BWSI

The Blue Water Scarcity Index (BWSI) is introduced in Hoekstra *et al*. (2012) and used to identify water consumption where it exceeds availability for human use. The original approach uses BWSI to identify water use in processes in regions where local consumption violates environmental flow requirements (BWSI > 1), and to identify the fraction of water used in such areas. This method sums the water volumes used in areas with BWSI > 1. This index is used to assess whether water use in a process occurs in a region where water consumption falls within the amount available for human activities. It is equivalent to the use of a CF of 0 (BWSI < 1) or 1 (BWSI > 1) for the calculation of a water scarcity category indicator, as described above.

BWSI is described as follows:

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

where demand refers to the sum of human water consumption (HWC) and environmental water requirement (EWR) and availability refers to the actual run-off (including human impacts – flow regulation and water use).

BWSI is without units, is computed on a monthly scale and is fully described in Hoekstra *et al*. (2012). It 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 metres or in a fraction of the total water consumption.

5.5 ADDITIONAL METHODS AND SENSITIVITY ANALYSIS

The choice of impact assessment methods influences the results of impact assessment. It is recommended that the two methods – AWARE and BWSI – be applied in order to follow best practice and provide useful sensitivity information on the choice of method. In addition to the two recommended methods, additional methods for water scarcity impact assessment may be used as part of sensitivity analysis. Alternative methods are listed in Appendix 6 and are available in the literature. Other water scarcity impact assessment methods exist and include both those used in the past and the upcoming ones for SDG 6.4.2.[3] This may be helpful for comparison with previous studies or with results from other initiatives. It is necessary to apply the same indicator consistently across the entire product system (and compared system when applicable).

5.6 ASSESSMENT OF WATER SCARCITY IMPACTS

Using the data collected (Chapter 4), potential impacts associated with water consumption can be calculated using water use inventory results and 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 BWSI.

[3] http://www.fao.org/sustainable-development-goals/indicators/642/en/

Figure 4
Hypothetical livestock product system (e.g. dairy product)

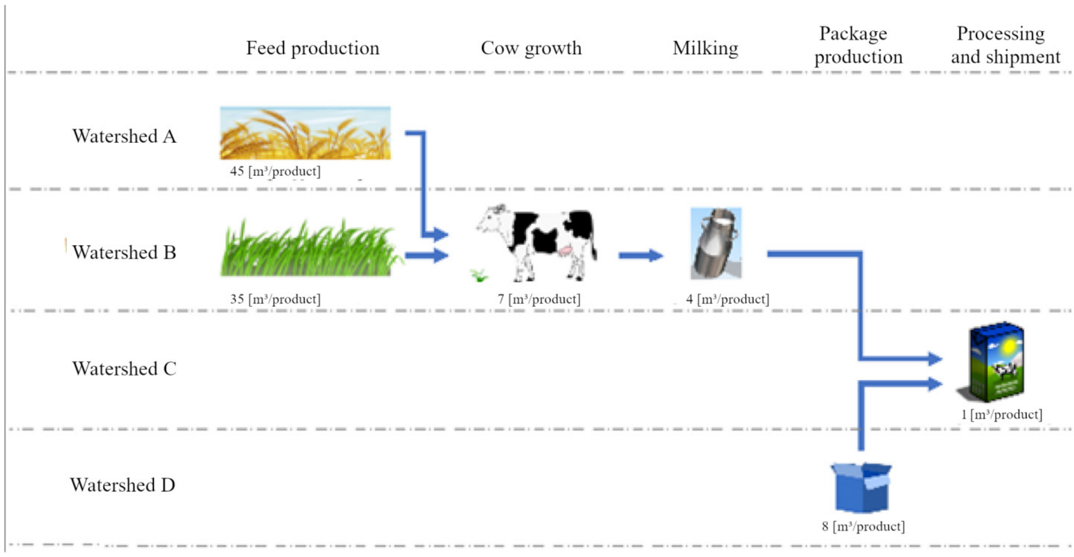


Table 7: AWARE and Blue Water Scarcity Index (BWSI) for a hypothetical livestock product system (e.g. dairy product)

	Inventory results	Scarcity factor		Impact assessment		
	Water consumption (m^3/product)	AWARE model ($m^3_{world\ eq.}/m^3$) (Boulay *et al.*, 2018)	BWSI (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 area concerned. The result of the impact assessment with the AWARE model quantifies, for 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 in a world average area, based on watershed A having 10 times less remaining water then the world average (CF = 10 $m^3_{world\ eq.}/m^3$).

When using BWSI as per Hoekstra *et al.* (2011), if the BWSI factor exceeds 1, 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 by a characterization factor) applies to most water use impact assessment models presented in Appendix 6 (Table A6.1).

5.7 IMPORTANT ASPECTS OF 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. The impacts of water consumption are local. They may involve increased scarcity, reduced river flows and lower groundwater levels, thereby affecting ecosystems and perhaps even human health through unavailability in areas where alternatives are not affordable or easily available. Water use impact assessments are primarily carried out at catchment level; this takes into account land sharing a common drainage basin and is the scale on which agriculture impacts water scarcity. While most water monitoring and reporting programmes operate at catchment level, modelling of an activity for the purpose of calculating emissions is done at farm level.

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 water footprinting is to reach a compromise between global and local data:

- **Global data** generally provide better coverage of background processes to the life cycle of livestock products. However, spatial resolution of data used for modelling the impacts tends to be lower than that of target processes. Global data may be more readily available, but the results produced may be less relevant than those obtained with local data.
- **Local data** consider specific, local conditions. Assessment methods based on local data are more relevant to and representative of the local situation. However, data collection for local-scale assessment requires additional effort and time, which represents a challenge for the application of high spatial resolution data on a global scale including background and upstream in the supply chain.

To meet this challenge, this guide proposes a tiered approach: Tier 1 adopts a global approach and Tiers 2 and 3 adopt local approaches (Chapter 3, Table 5 and Appendix 8).

Temporal coverage should account for the temporal variability associated with all processes of water use and water consumption through the life cycle of livestock products. For agricultural products, the average data of at least one year should be used so that seasonal variations during the year are accounted for; it is recommended to have data from multiple years to account for inter-annual variation.

5.8 WORKING TOWARDS IMPACT ASSESSMENT OF GREEN WATER CONSUMPTION

5.8.1 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 and, as such, 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, 2008). Where a livestock production system leads to a change in green water flows compared with an alternative land use or land management system, water use impact assessment may be considered for this difference, subject to the necessary precautions.

5.8.2 Decrease in green water flows to the atmosphere

Where land use change or land management leads to a reduction in evaporation or transpiration from the land, the result may be an increase in drainage and run-off, potentially increasing the local availability of blue water. In such cases, it is possible to assess the positive impacts on blue water availability using the models described in section 5.4. However, there are at least three complicating factors:

- Assessment of the impacts of a change in evapotranspiration (ET) requires the selection of a reference land use/land management state. Potential natural vegetation is one possibility (Núñez *et al*., 2013; Ridoutt *et al*., 2010). However, this reference state is not necessarily appropriate for all policy and decision-making contexts.
- 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 lack of water use impact assessment methods addressing potential impacts on ecosystem services from land use change; those that have been proposed are limited in scope and yet to be widely adopted.
- Apart from local impacts on water availability, changes in ET have the potential to impact atmospheric moisture recycling on larger scales, referred to as precipitation sheds (Keys *et al*., 2012). A land use or land management change that alters the local ET flow can have local, regional and even continental impacts on precipitation (Ellison, Futter and Bishop, 2012; Berger *et al*., 2014; Launianen *et al*., 2014; Harding *et al*., 2013; Keys, Wang-Erlandsson and Gordon, 2016; Lathuillière, Coe and Johnson, 2016).

There are major uncertainties associated with modelling these processes, as different climate models are likely to deliver different results.

5.8.3 Increase in green water flows or green water interception

Where a change in land use or land management leads to an increase in evaporation or transpiration or to the diversion of green water flows, there may be a decrease in drainage and run-off 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 section 5.6 are recommended.

5.8.4 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. **Measures include:**

- terracing and the creation of furrows to increase water infiltration into the soil and reduce overland flows and soil erosion;
- application of different irrigation technologies and strategies (e.g. precision or deficit irrigation) to optimize water use efficiency;
- management of soil cover to avoid soil loss and unproductive green water evaporation (e.g. conservation tillage, manuring and mulching) (Chukalla, Krol and Hoekstra, 2015); and
- management of soil health to increase soil organic matter and water-holding capacity.

Soil and water conservation measures produce many **potential benefits:**

- improvement of local productive use of soil moisture;
- provision of support to groundwater recharge for the benefit of downstream communities and ecosystems; and
- reduction of erosion, lessening the sedimentation impacts experienced by downstream water users and ecosystems (Quinteiro *et al*., 2015).

Soil and water conservation measures are especially important in arid and semi-arid regions where rainfall during the cropping period may be inadequate or marginal and cropping success depends on stored soil moisture (Hunink *et al*., 2012; Scheepers and Jordaan, 2016). Nevertheless, apart from the direct benefits on crop yield at the site where the soil and water conservation measures are practised, it is not always simple to quantify the impacts spatially and temporally (Jewitt, 2006; Hunink *et al*., 2012); indeed, no recommendations regarding water use impact assessment models can be made at this time to capture this. In order to support improved agricultural practices and the implementation of policies linking water users within a catchment for their mutual benefit (e.g. payments for ecosystem services), it is strongly recommended to carry out further impact assessment research on this topic.

To improve water productivity, it is possible to adopt **productive and agronomic best practices**, including (Doreau, Palhares and Corson, 2013):

- know all environmental legislation related to the activity and to the management of water resources and soil;
- use inputs considering all environmental, technical and productive conditions, and analyse soil fertility;
- monitor soil agronomic features (pH, nutrient and mineral soils content, and texture), temporal conditions, and soil/crop nutrient status and evaluate if it is optimal for the crop;
- adopt soil conservation practices, including winter cover crops, and appropriate tillage practices;
- have a nutrient management plan; and
- consider agricultural and ecological zonings.

6 Assessment: Water productivity

6.1 CALCULATING WATER PRODUCTIVITY

Water productivity (WP) is used as a measure to relate the livestock product system value (e.g. kg of meat, litres of milk, number of eggs, calories or protein content of food products, or economic value) to its water consumption (Molden, 1997; Molden *et al.*, 1998; Molden and Sakthivadivel, 1999; Descheemaker, Amede and Haileselassie, 2010; Peden *et al.*, 2009; Prochnow *et al.*, 2012). WP may be calculated using the different livestock product system values depending on the scope of the study (Table 8).

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

$$WP_{mass} = \frac{Mass_{output}}{Q}$$

or

$$WP_{mon} = \frac{Revenues_{output}}{Q}$$

or

$$WP_{energy} = \frac{Food\ energy_{output}}{Q}$$

where:
WP_{mass} is water productivity on mass base (kg_{FM}/m^3 Q, kg_{DM}/m^3 Q)
FM is fresh matter
DM is dry matter
WP_{energy} is water productivity on a metabolizable food energy base (MJ/m³ Q)
$WP_{protein}$ is water productivity on a protein content base (kg/m³ Q)
WP_{mon} is water productivity on a monetary base (USD/m³ Q)
Q is water consumption (m³/yr)
$Mass_{output}$ is mass output (kg_{FM}/yr, kg_{DM}/yr)
$Energy_{output}$ is food energy output (GJ/yr)
Revenues is total revenues (USD/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 gain an idea of 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:

$$WP_{indirect+direct,Farm} = 0.292\ kg_{cw}/m^3\ (0.3\%/99.7\%)$$

(Drastig *et al.*, 2013).

Water productivity shall be determined for individual inputs and subprocesses within the system (e.g. feed production and for products leaving the farm gate) and optionally for the livestock production system overall. 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 tonne 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, for example, farm output as kg of fat and protein corrected milk (FPCM) per year over Q as:

$$Q_{Farm} = Q_{Feed,ET} + Q_{Animal} + Q_{Housing}$$

Depending on the 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). WP_{direct} 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. if direct water consumption of different foreground facilities 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 to track the performance of the system.
- **$WP_{direct+indirect}$ – indirect + direct water productivity** (in output unit per m^3). $WP_{direct+indirect}$ is calculated on more than one unit process and life cycle stage 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 kg live weight/m^3 water over the entire supply chain.

In general, the goal and scope of the water use assessment guide the water productivity assessment. However, the $WP_{direct+indirect}$ metric shall always be accompanied by WP_{direct} for all individual parts of the system, as well as the water scarcity footprint (section 5), in order to prevent misguided decisions which would not represent an environmental improvement (e.g. if a higher productivity is associated with a higher water scarcity footprint).

6.2 CALCULATING FEED WATER PRODUCTIVITY

Feed crop WP shall be estimated based on the ratio of the yield of the field (cropland or pasture) and the evapotranspiration (ET) from the field (from harvest of the previous crop through to harvest of the crop). ET from cropland and pasture results from the consumption of green water (in rain-fed systems) or of a combination of green and blue water (in irrigated systems) (subsection 4.4.1 "Water balances of feed production" and Table 8).

Transpiration is the productive part of ET's contribution to biomass build-up. **Evaporation** is the unproductive part of ET (evaporation of water intercepted by the plant canopy and evaporation directly from the soil). The unproductive part can be seen as a "loss" but can be included in the WP calculation; the equation thus captures all water use and the water productivity metric reflects improvements in terms of reducing unproductive evaporation.

Ruminant animal production systems often involve animal grazing. Green water consumption of rangeland and cropland shall be distinguished as the water productivity varies. Rangeland might have no use other than grazing. It is possible to highlight this issue and the related opportunity cost by distinguishing between green water use by "rangelands not suitable for crop production" and green water use by "croplands" and "rangelands potentially suitable for crop production".

Table 8: Definition of water productivity metrics of unit processes[1] for feed production,[2] animal production[3] and primary processing on a mass basis

Stage/Scale	Output	Q	Metric (kg/m³) (blue water/green water)
Feed production: on farm			
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) (%/%)
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) (%/%)
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) (%/%)
Feed production: 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) (%/%)
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) (%/%)
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) (%/%)
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) (%/%)
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) (%/%)
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) (%/%)
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%)

Notes:

[1] WP = water productivity.

[2] Includes WP for both on-farm production and purchased feed.

[3] Includes WP for on-farm production and purchased feed, animal breeding.

The calculation of water productivity requires detailed knowledge of water resource use of processes and products in different watersheds. This information shall be gathered following the recommendations for water use inventory (Chapter 4). Considering that livestock contributes 17 percent to the global food balance (in terms of caloric intake per person per day) and accounts for 33 percent of the protein in human diets (Herrero and Thornton, 2013), the sector's WP may also be measured in terms of caloric or protein value. When considering economic value, it is possible to consider economic value added (e.g. in USD); this may be obtained from the product's contribution to gross domestic product (GDP) or from average global market prices.[1]

Water productivity based on monetary farm output

- ***USD – a simple unit*** *– is one option for estimating water productivity. This choice is in line with the United Nations Sustainable Development Goal on Water, which proposes use of a standard and homogeneous unit for measuring the indicator.*
- *The use of USD can be disputed as a measure of value of livestock: the valuation is subject to* ***fluctuations in exchange*** *rates and 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: consideration of* ***global average market prices and internationally traded volumes*** *of the livestock product under study.*

6.3 CALCULATING WATER PRODUCTIVITY FROM ENERGY AND OTHER INPUTS

The water productivity of other unit processes of the livestock production system – 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) and Quantis (Quantis, 2012), or from tools such as the WBCSD global water tool (WBCSD, 2015), and used to calculate the WP.

[1] Another framework for assessing monetary values is https://unstats.un.org/unsd/envaccounting/seeaw/seeawaterwebversion.pdf

7. Interpretation of results

When interpreting the results, the aim should be to help different types of decision-makers understand how their product system relates to water use so that they may achieve more efficient and sustainable ways of producing livestock and consuming water from the perspective of both water as a resource and the overall environmental impact of water use. In terms of the environmental impacts, the results point to the urgency to act, while with regard to water productivity, there is room for improvement. It is important to interpret the results in light of who is going to use the report and for what purpose. The interpretation should highlight which points in the production chain can be improved to minimize impacts, as identified in Chapter 5, with respect to water scarcity and production efficiency related to water use. Interpretation must clarify the level of aggregation used in the result chapter, that is, interpretation of results for different types of water use (green and blue) should be presented separately and put in the context of each other. The source literature of the methods decribed in Chapter 5 provides a comprehensive presentation of how to interpret water use impact assessment.

7.1 Result of water use impact assessment

The results of the water use impact assessment provide insight into 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:

- **Water scarcity footprint** – quantifies the potential user deprivation and potential environmental impacts associated.
- **Blue water scarcity** – 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 the water use impact assessment shall be analysed from both an aggregated and disaggregated perspective along the life cycle of livestock production and livestock products. Aggregated impact assessment results present the overall performance of the target related to physical water scarcity, whereas disaggregated results demonstrate the contribution of each stage and process to water scarcity.

The **water use inventory analysis** should indicate:

- water consumption for each process stage (life cycle stage) in the supply chain;
- total water consumption of all processes, providing temporal reference and location within the drainage basin; and
- source of water used (e.g. surface or groundwater, rainwater).

The **water use impact assessment** should provide answers to the following questions:

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

- Where and when does the water consumption exceed the flow allocated to humans due to basin-specific attributes? (e.g. using BWSI)
- What fraction of the water consumption in such basins already exceeds the allocated share to humans? (e.g. using BWSI)

Detailed analysis of the system

Detailed results of the impact assessment using water scarcity footprint in 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 from the benchmark, assessment of water productivity will serve to find solutions to reduce water consumption in a process (section 4 and section 7.2). If the geographical location (i.e. characterization factors of the area) is more influential, an alternative site for the production process could be sought. However, it may not be feasible to change the location of the process concerned, because socio-economic impacts might be high and need to be taken into consideration 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.

Those components of the blue water consumption of a product/process which contribute the most to impacts, or which are unsustainable, deserve action in order to improve the situation. Such action will be based on the share of a given water consumption in the potential impacts and decided according to priorities, for example:

- disregard components contributing to the overall potential impacts below a certain threshold (e.g. 1 percent);
- take into account the relative severity of the various hotspots to which the different water consumptions contribute; or
- consider 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 understand the improvement of the livestock system in quantitative terms and with respect to physical water scarcity. While water use inventory analysis results may indicate that a process increases water use in region A and another process decreases water use in 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 of water scarcity in different areas with the same metrics, enabling the assessment of 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 as resulting 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 than available water for human use implies that the product/process is using the environmental flow required by the ecosystems. These regions represent hotspots requiring special consideration.

7.2 RESULT OF WATER PRODUCTIVITY ASSESSMENT

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 that are closely related to differences in farmers' livelihood strategies of the respective livestock or poultry systems. Haileslassie *et al.* (2009) reported water productivity values of USD 0.15–0.69/m³ for mixed farming systems integrating both crops and livestock, typical of the Gumera watershed (Ethiopia). Farmers keep cattle (*Bos indicus*), sheep (*Ovis aries*), goats (*Capra hircus*), horses (*Equus caballus*) and donkeys (*Equus asinus*). The authors suggest that feed, age, breed and herd structure account for variability in WP. There can also be marked variation between and within feed crops. The differences between feed crops on a mass base can be attributed mainly to differences in 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 productivity of between 0.34 and 4.02 kg FM/m³ Winput; in contrast, feed crops with lower biomass production, such as semi-arid rangelands, grains or rapeseed, have much lower water productivity of between 0.15 and 2.16 kg FM/m³ Winput (Descheemaker, Amede and Haileselassie, 2010; Prochnow *et al.*, 2012). In addition, the food energy-based water productivities of feed crops vary according to food energy content. For example: for sugar beet, high yield of food biomass combined with high food energy content results in energy-based water productivity about 6–20 times higher than that of other crops; for rapeseed, low yield is counterbalanced by the high food energy content of rapeseed oil; and grains are characterized by food energy-based water productivities in the lower range. The farmer's decision on which crops to grow and which livestock to keep depends mainly on natural conditions and the general economic framework (Prochnow *et al.*, 2012).

It is not meaningful – either from a nutritional or from an agronomic perspective – to attempt to improve water productivity by growing feed crops with high water productivity. Improvement of a farm's water productivity must focus on the major differences in water productivity between fields with the same feed crops. Such differences can be attributed to marked variation in yields reflected in the wide range of outputs of biomass, food energy and revenues. Given that all fields receive the same amount of precipitation per hectare, the variation illustrates that farm output – and thus water productivity – is determined not only by water but also by many other factors, such as soil quality and soil management practices (Prochnow *et al.*, 2012). Improvement of water productivity at process, field, farm and basin level, regardless of whether the crop is grown under rain-fed or irrigated conditions, is based on the following key principles:

- Increase the marketable yield of the crop for each unit of water it transpires.
- Reduce all outflows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop stomatal transpiration.
- Increase the effective use of rainfall, stored water and water of marginal quality (http://www.fao.org/docrep/006/y4525e/y4525e06.htm and Appendix 8).

7.2.1 *Analysis of irrigation scheme*

When analysing an irrigation scheme, it is important to use unambiguous terminology. 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 on all scales. Perry (2011) proposed an analytical framework and associated terms to meet the needs of technical specialists from all water-using sectors, policymakers and planners seeking more productive use of water. The terminology should distinguish between the fraction consumed (including beneficial and non-beneficial) and the fraction not consumed (including recoverable and non-recoverable).

The efficiency of an irrigation scheme can be increased by reducing non-productive water losses, such as soil evaporation losses (Hess and Knox, 2013; Perry, 2011). Moreover, an irrigation scheme should minimize non-consumptive water loss through percolation while ensuring that sufficient water percolates to clean salts from the soil. Changing the irrigation system (e.g. from furrow to drip irrigation) is one way of reducing the above-mentioned water losses. In addition, it is important to verify that the timing and dosage of irrigation is appropriate and corresponds to the crop's needs. Periods of water lodging or water stress can negatively affect final yield, depending on the crop's sensitivity to saturated or water-scarce conditions. Therefore, farmers must have good knowledge of the water requirements during crop growth to avoid erroneous agricultural practices. The option exists of crops not receiving full water requirements and of deficit irrigation programmes being adopted to optimize the crop water productivity.

7.2.2 *Comparison of water productivity assessment results*

Any comparison of WP results – whether between product systems or within the same product system – shall be based on the same WP metrics. The **interpretation of the assessment** should reveal the following:

- any potential to improve the effectiveness of water consumption;
- respective shares of blue water, green water and combined to enable decision-making with regard to green and blue water allocation in all stages of livestock production system; and
- possible measures for improving the situation if water productivity is below the benchmark (i.e. production is not efficient: the water requirement to produce exceeds the benchmark) – for example, identification of hotspots.

Depending on the goal of the assessment, the interpretation should also highlight the geospatial and temporal scales adopted when developing the benchmarks. **Benchmark comparison** should consider the same production conditions: agricultural (climate, soil, genetic and farming practices); animal-related (production system, climate, genetic, nutritional management, type of barns, and technologies and practices for servicing water); and other.

When data for these parameters are limited, this should be clearly indicated Comparison between different production contexts will lead to errors in the interpretation; therefore, mitigation practices must not be based on such comparisons.

7.2.3 *Identification of response options*

The interpretation of the assessment could influence the decision-making process to optimize water use, technologies, geographical locations and agricultural and livestock management, in terms of both water productivity and reduction of

Table 9: Water productivity versus levels of scarcity footprint matrix to guide priority setting

	Low scarcity footprint	Medium scarcity footprint	High scarcity footprint
High water productivity	0	0	+
Medium water productivity	0	+	++
Low water productivity	+	++	+++

Notes:
0 = low priority; +++ = high priority.
Source: Hoekstra *et al*. (2011) – Table 5.2 (adapted).

potential environmental impacts. It should highlight and help detect areas of opportunity for adapting livestock production (increasing efficiency) or identify where mitigation measures could be applied within the production chain. Furthermore, the socio-economic context needs to be accounted for; for example, extensive livestock systems in arid regions already depend on scarce water and these systems are major contributors to the food security and livelihoods of pastoralists, and this information needs to be included in the analysis.

As the response options depend on complex sets of variables (basin attributes, size and type of footprint, production process and available best practices), only a limited number of top-level response options are presented in Appendix 7.

The first step in response formulation is 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.

A systematic approach (Figure A7.1) is adopted to prioritize and identify response options. Possible **questions:**

- 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)?

Various components and their combinations comprise the possible **responses:**

- 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-sectoral collaboration).
- Innovation (developing opportunities).

7.3 UNCERTAINTY AND SENSITIVITY ASSESSMENT

Variability and lack of measured data often result in uncertain data (Chapter 3); for this reason, data require uncertainty information. This applies also to 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 generally be classified as: input data uncertainty and model uncertainty, in addition to choice uncertainties, which are not usually reported in LCA studies (Verones *et al*., 2017). A recent UNEP report on guiding LCA (Frischknecht and Jolliet, 2017) highlighted the need for quantitative uncertainty data whenever possible, while acknowledging that it is usually not practicable.

Input data uncertainty refers mainly to measured or modelled parameters retrieved from other studies and includes, for instance, climate data, which can vary significantly when modelling on a 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 different results. For water consumption, uncertainties are often especially high (Pfister *et al*., 2011), as shown by 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 are assigned a high uncertainty value (in the range of +/–40 percent for the 95-percent interval) in Ecoinvent 3 (2015), an LCA inventory database that includes water flows and balance for approximately 10 000 industrial and agricultural processes (Pfister *et al*., 2016).

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

Therefore, in the interpretation of the results, it is very important to account for uncertainty of the different inputs to the analysis in order to: 1) enable discussion of those uncertainties – at least qualitatively; and 2) test alternative options in sensitivity analysis. Uncertainty information can help determine a meaningful range for sensitivity assessments beyond the use of different methods suggested for the water use impact assessment.

The **sensitivity assessment determines:**

- 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 the improvements from alternative options are in terms of water productivity and water footprint; and
- where better data collection would produce more reliable results.

Correlated uncertainty (e.g. 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.

8. Reporting

8.1 PRINCIPLES FOR REPORTING

- **Credibility and reliability.** To improve environmental understanding of products and processes, it is important to maintain technical credibility while providing adaptability, practicality and cost–effectiveness of the application. Reporting conveys information that is relevant and reliable in terms of addressing environmental areas of concern (adapted from ISO 14026 – ISO, 2015).
- **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 about where the data originated and how they were 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.

8.2 REQUIREMENTS

- Reporting of impacts and water productivity assessment results shall be performed without bias and in line 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 to 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 detail 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 – making available the information about each separate elementary flow – as should be the data sources:
  - Aggregation of water productivity data (e.g. water use data from different locations) shall not be reported without the water scarcity footprint (ISO 14046 – ISO, 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 (ISO, 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 (ISO, 2006a).
- 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) occurring over time shall also be reported.

8.3 GUIDELINES FOR REPORT CONTENT

Depending on 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 target 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 study.
- Cut-off criteria.
- Allocation method(s) and justification if different from 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 production and processing systems, with justification.
- Feed intake and application of LEAP feed and animal guidelines.
- Life cycle inventory (LCI) modelling and calculating of LCI results reported separately for different locations and time spans when applicable.
- Results and interpretation of the study and conclusions.
- Description of opportunities for water-related environmental performance improvement.
- Description of limitations and trade-offs.
- Description of the benchmark(s) used as reference in the assessment.
- Clear reference to baseline year and any eventual changes occurring over time – in the case of performance tracking.

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.

8.4 THIRD-PARTY REPORTING

A third-party report is a report meant to include information to be communicated to third parties (i.e. interested parties other than the commissioner or the practitioner of the study) (ISO 14044 – ISO, 2006a). 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.** Further, to guarantee credibility and transparency of the study, a critical review according to ISO 14071 (ISO/TS, 2014) should be performed.

In addition to internal report requirements, **the following requirements shall be applied to third-party reporting:**

- 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 for describing the overall potential environmental impacts of products.

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APPENDIXES

Appendix 1

Functional units and reference flows

Table A1.1: List of functional units and reference flows

Livestock	Stage	Functional unit/Reference flow	Corresponding LEAP animal guidelines
Piglet	Farm gate	Live weight (kg)	FAO (2018) (p. 37)
Spent snow	Farm gate	Live weight (kg)	FAO (2018) (p. 37)
Draught power	Farm gate	MJ	FAO (2016a) (p. 33)
Milk (large and small ruminants)	Farm gate	FPCM1 (kg), ECM2 (kg)	FAO (2016a) (p. 33), FAO (2016b) (p. 28)
Milk (large and small ruminants)	Processing gate	Fat/protein content (kg), milk product (kg)	FAO (2016a) (p. 33), FAO (2016b) (p. 28)
Egg	Farm gate	Fresh shelled weight (kg)	FAO (2016c) (p. 30)
Egg	Processing gate	Liquid or dry (powder) weight (yolk, whole, white) (kg)	FAO (2016c) (p. 30)
Fibre (small ruminants)	Farm gate	Greasy weight (kg)	FAO (2016b) (p. 28)
Fibre (small ruminants)	Processing gate	Clean weight (kg)	FAO (2016b) (p. 28)
Meat	Farm gate	Live weight (kg)	FAO (2018) (p. 37)
Meat	Processing gate	Meat product, Carcass weight (kg)	FAO (2018) (p. 37)

Notes:
[1] FPCM – Fat and protein corrected milk.
[2] ECM – Energy corrected milk.

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Appendix 2
List of models

Table A2.1: List of models

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 Program designed to simulate transport processes at field-scale level and during entire growing seasons	SWAP (Soil–Water–Atmosphere–Plant)	http://www.swap.alterra.nl/
Simulates yield response of herbaceous crops to water Point- or site-specific applications	AQUACROP (FAO) (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	CROPWAT (FAO) (Smith, 1992)	http://www.fao.org/nr/water/ infores_databases_cropwat.html

Note: Most of the proposed models need expert users for meaningful application.

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Appendix 3
Tables on water balances for swine production

Table A3.1: Water balance for swine production: *Example I*

Source	Source description	Use description	Volume (litres/pig)	Uncertainty (SD or range)
Inputs (source and use)				
Groundwater (stock)	Blue water	Piggery water supply (including 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 contribution to the feed system		26	1.43
Pigs (purchased pigs brought to farm)			1	1.43
Total inputs			**481**	

Source: Wiedemann, McGahan and Murphy (2012, 2017).

Table A3.2: Water balance for swine production: *Example II*

Source	Source description	Use description	Volume (litres/pig)	Uncertainty (SD or range)
Outputs (source and use)				
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	

Source: Wiedemann, McGahan and Murphy (2012, 2017).

Table A3.3: Inputs (source and use)

Source	Source description	Use description	Volume (litres/weaned)	Volume (litres/porker)	Volume (litres/finished pig)
Effluent from piggery	Combined sources – excretion and cleaning	Manure treatment	624.8	666.2	1 495.7
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**	**1 918.2**
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	1 083.6
Total outputs			**787.6**	**832.1**	**1 918.2**
Balance			0.0	0.0	0.0

Source: Wiedemann, McGahan and Murphy (2012, 2017).

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Appendix 4

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

Table A4.1: Drinking water demand chicken

Chicken broiler age (weeks)	Water requirement (litres/1 000 birds/day)	
	21 °C	32 °C
1–4	50–206	50–415
5–8	345–470	550–770

Source: OMAFRA, 2015 (adapted).

Table A4.2: Drinking water demand swine – water requirements (litres per pig per day) for swine

Class	Water intake (litres/pig/day)
Nursery (≤ 27.2 kg)	2.6–3.8
Grower (27.2–45.3 kg)	7.6–11.3
Finishing (45.3–113.4 kg)	11.3–18.9
Non-pregnant gilts	11.3–18.9
Pregnant sows	11.3–22.7
Lactating sows	18.9–26.5
Boars	11.3–22.7

Source: NDSU, 2015 (adapted).

Table A4.3: Drinking water demand small ruminants (litres per head)

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

Source: DAF (2014).

Table A4.4: Drinking water demand cattle when the daily high temperature is 32 °C (litres per head)

Type of cattle	Daily litres required per 45 kg of body weight
Growing/Finishing Cattle	8
Dry cow	4
Cow – Calf pair	8
Bull	4

Source: UGA, 2012 (adapted).

Table A4.5: Drinking water demand dairy cattle (litres per head)

Dairy cattle type	Level of milk production (kg milk/day)	Water requirement range (litres/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

Source: OMAFRA, 2015 (adapted).

Table A4.6: Meat processing impacts associated with processing four different species, expressed as per kg of hot stand carcass weight (HSCW)

Livestock species	litres/kg HSCW
Chicken meat	2.43
Pork meat	6.57
Sheep meat	7.53
Beef meat	8.75

Source: Wiedemann and Yan (2014).

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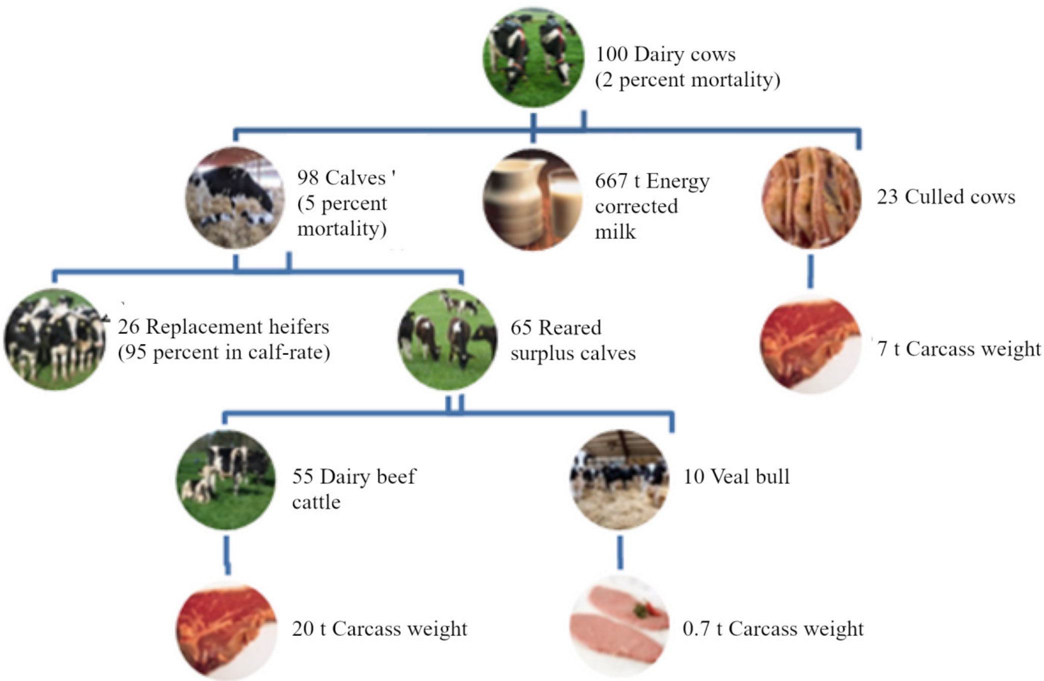
Appendix 5
Inventory assessments

Figure A5.1
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)



Note: Based on breeding 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 percent for culled cows and 59 percent 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.
Source: FAO. 2016a. Environmental performance of large ruminant supply chains: Guidelines for assessment. Livestock Environmental Assessment and Performance Partnership. Rome, FAO.
(also available at http://www.fao.org/3/a-i6494e.pdf).

Appendix 6

Blue water scarcity indicator

Table A6.1: Blue water scarcity indicators (in chronological order of publication)

References	Type of indicator
Falkenmark and Lindh (1974)	Withdrawal-to-availability (WTA) ratio, with thresholds defined
Raskin *et al*. (1997)	WTA ratio, with thresholds defined
Water exploitation index (WEI) EEA (2003)	WTA ratio, with thresholds defined
Water stress indicator (WSI) Smakhtin *et al*. (2004) Mila i Canals *et al*. (2009)	Withdrawal-to-(availability – EWR) ratio (EWR = environmental water requirement)
Use-to-Qxx ratio Alcamo, Flörke and **Märker** (2007)	Consumption-to-Q90 ratio (Q90 = discharge that is exceeded 90% of the month)
Water stress index (WSI) Pfister, Koehler and Hellweg (2009) Pfister and Bayer (2014)	Based upon WTA, scaled between 0.01 and 1 Adaptation to monthly level
Swiss ecological scarcity Frischknecht and Büsser Knöpfel (2013) Update of Frischknecht and Jungbluth (2009)	Based on WTA ratio, converted to eco-points
Use to environmentally available water Vanham, Fleischhacker and Rauch (2009a,b)	Withdrawal-to-(availability – Q95) ratio (Q95 = daily discharge that is exceeded 95 percent of the month)
Wada *et al*. (2011)	WTA ratio (WTA), with thresholds defined
Water scarcity parameter α Boulay *et al*. (2011)	Based on consumption-to-Q90 ratio, modelled 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 (EWR = 80 percent of the total run-off) 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, modelled 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

(Cont.)

References	Type of indicator
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 including uncertainties
Water stress Vanham *et al*. (2018)	Recommendations for application of SDG 6.4.2 on water stress indicator.
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 WRI (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

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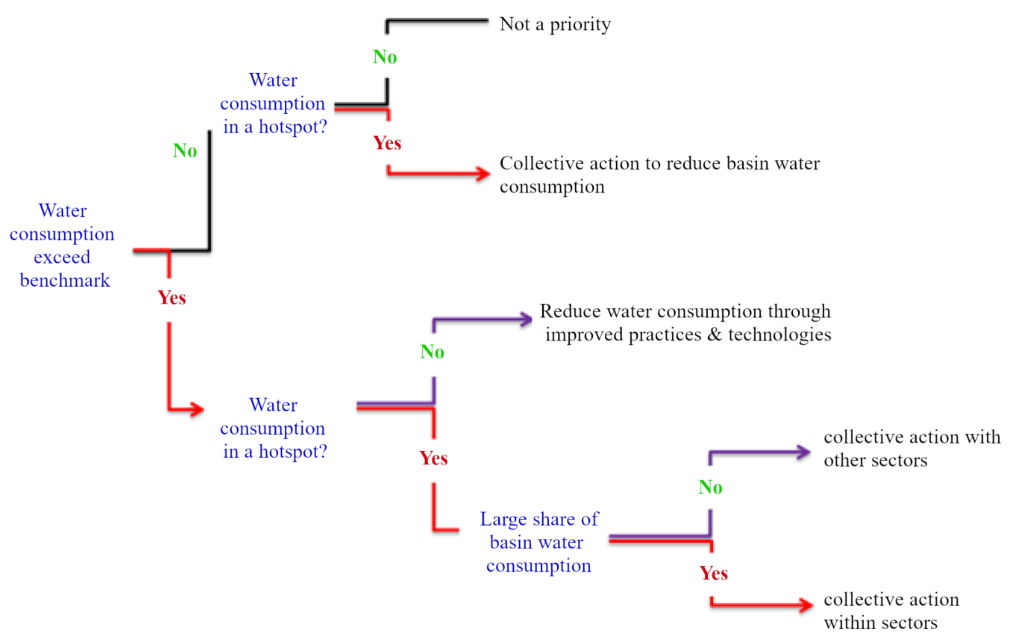
Appendix 7

Decision tree on response options

Figure A7.1

Systematic approach for prioritization and identification of types of response options



Appendix 8

Farming measures to increase livestock water productivity

Along the livestock production–consumption chain, there are many opportunities to improve water productivity, and many options are indirectly related to water. Animal health is one important example to increase overall production, and thereby 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, crop water productivity increased by at least 100 percent between 1961 and 2001 (Kijne, 2003). The major factor behind this growth was yield increase. For many crops, the yield increase 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 regard to water demand in dairy systems, feeding strategies and milk yield optimization are identified by Krauß *et al*. (2015) as particularly important measures to substantially raise water productivity 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 swine 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 percent for these diets. For each litre of water used, 179 kcal were generated to the conventional diet and 218 kcal to the three nutritional strategies. Results indicate that the use of nutritional strategies provides swine production that is more conservationist in terms of 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, for example, 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 (e.g. water bowls, bite type drinkers, nipple drinkers or animal-operated valves), and maintenance and repair of water troughs to eliminate leaks. The use of shade on waiting yards or feed yards maintains the moisture in faeces and urine, reducing the use of water. In addition, this practice is good from an 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 *et al*., 2011).

Increase in water productivity of cleaning processes:

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

Reduction of drinking water consumption (with animal welfare as high 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 management:

- Proper formulation of diets in order to avoid excessive water consumption, feed intake and excretion of nutrients.
- Maximization of use of roughage feeds to decrease the pressure on freshwater resources.
- Attention to roughage–concentrate ratio and type of roughage – the nutritional aspects that most significantly influence the footprint values to ruminants.
- Use of nutritional technologies (amino acids, enzymes etc.) to improve nutrient-use efficiency and animal 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 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 recycling depend on the quality of the water after the first use.

The key principles for improving water productivity depend on the production or subproduction systems under consideration and the geographic extent under study (field, farm and basin levels). For instance, water productivity of feed may be improved by:

- increasing the marketable yield of the crop for each unit of water transpired, possibly by selecting a more efficient crop variety;
- reducing all outflows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop stomatal transpiration; and
- increasing the effective use of rainfall, stored water and water of marginal quality.

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Appendix 9

Data quality and relation to uncertainty assessment

Data quality can be limited if secondary data are used (compare Chapter 3 on 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 are various aspects of data quality, a generic approach used in life cycle assessment (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 (Chapter 3). The quality criteria are put in rows and the quality rating in columns as presented in Table A9.1. 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 obtain the 95 percent confidence interval: [$\mu/GSD^{1.96}$; $\mu * GSD^{1.96}$]. These scores are also referred to as k value (dispersion factor) by Slob (1994), who generalizes this concept also for non-log-normally distributed data. The total uncertainty factor of each data point ($GSD^{1.96}_{total}$) is calculated as follows based on the scores in Table A9.1:

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

Table A9.1: Proposed approach to derive uncertainty from data quality and suitability information

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 production 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

Source: Weidema and Wesnaes (1996) in Goedkoop *et al.* (2016).

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