ISO 14046
Water Footprinting and Water Impact Assessment in LCA
Adjusted from UNEP training materials on water footprint (Pfister and Boulay 2013)
AGENDA TODAY

• Introduction 20 min
  – WULCA Presentation
  – Why a water footprint?
• Water and LCA 15 min
• ISO 15 min
  – Process
  – Standard content
• Structure and types of WF 10 min
• Inventory and example 40 min
  Break 20 min
• Overview of methods and examples 1h15
• Tools 10 min
Water Use in LCA (WULCA)

• International initiative for LCA founded in 2007 under the UNEP-SETAC Life Cycle Initiative

Goal: Recommendations for:
  – Science
  – Practitioners (incl. industry)

Output (no officially endorsed documents):
  – **Phase 1**: Proposed a framework to evaluate water in LCA (Bayart et al. 2009)
  – **Phase 2**: Review of different methods (Kounina et al. 2012)
  – **Phase 3**: Quantitative comparison (Boulay et al A and B, submitted)
Transition into Phase 3 and official acceptance from Life Cycle Initiative in Spring 2013

New chairs, new strategy, new speed!

Water was identified in Glasgow as a Flagship category from the Global Guidance Flagship categories from UNEP SETAC Life Initiative and WULCA received the mandate to lead the project.

Anne-Marie Boulay
Project Manager

Stephan Pfister
Deputy Manager

www.wulca-waterlca.org
Phase 3 Main goals:

- Guide the scientific development of a consensual and operational method which shall be in line with both the ISO Water Footprint Standard and the LCA principles.

- Provide guidance to practitioners and researchers in their understanding of comprehensive water footprinting.

- Represent the scientific voice on water footprinting.
  - Provide scientific support and guidance to the ISO 14046 TR.
  - Influence international initiatives (e.g. CEO Water Mandate, WRI activities etc.) + conferences and trainings.
We are currently forming a group of sponsors to support the advancement of this project.

Contact us if you are interested to join!

Anne-marie.boulay@polymtl.ca
WHY A WATER FOOTPRINT?
Former Aral Sea, Central Asia

Cotton for export

Source: WFN, 2012
Endangered Indus River Dolphin

[Photo: WWF]

Source WFN, 2012
THE HUMAN RIGHT TO WATER AND SANITATION

• UN assembly acknowledged this explicitly in 2010:
  – 64/292. The human right to water and sanitation

MOTIVATION FOR ASSESSING A WATER FOOTPRINT

• Water scarcity is one of the most important environmental problems
• Increasing population is aggravating water problems
• Sustainability has become a key marketing factor
• Public pressure and operational risk make it relevant for business to assess the following risks (beyond “green pioneers”):
  – Physical
  – Regulatory
  – Reputational
Water footprint is agreed to be a life-cycle based assessment (UNEP 2012):
- Water use of total supply chain, use and disposal is assessed

Water footprint is accounting for quantity and quality issues of water use (ISO 14046 draft) related to products, services or whole economies

Advanced water footprint assessment needs to be largely based on Life Cycle Assessment (LCA) methodology for assessing impacts of pollution
WATER RESOURCES

Natural cycle and man-made issues
Hydrosphere - Volumes

All water resources 1.4 billion km³

- Vapor 13’000 km³
- Saline water 1.4 billion km³
- Fresh water 35 million km³ (2.5%)
  - Liquid 11 million km³ (<1% of all water resources)
  - Solid (ice) 24 million km³

Ground & Surface water (Blue water sources)
- 90’000 km³ lakes
- 2’000 km³ rivers
- 10.5 million km³ groundwater

Living matter & soil moisture (Green water sources)
- 16’000 km³ soil moisture
- 1’000 km³ living matter

### Global Average Renewal Rates

<table>
<thead>
<tr>
<th>Water of hydrosphere</th>
<th>Period of renewal</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Ocean</td>
<td>2,500 years</td>
</tr>
<tr>
<td>Ground water</td>
<td>1,400 years</td>
</tr>
<tr>
<td>Polar ice</td>
<td>9,700 years</td>
</tr>
<tr>
<td>Mountain glaciers</td>
<td>1,600 years</td>
</tr>
<tr>
<td><strong>Ground ice of the permafrost zone</strong></td>
<td><strong>10,000 years</strong></td>
</tr>
<tr>
<td>Lakes</td>
<td>17 years</td>
</tr>
<tr>
<td>Bogs</td>
<td>5 years</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>1 year</td>
</tr>
<tr>
<td>Channel networks</td>
<td>16 days</td>
</tr>
<tr>
<td>Atmospheric moisture</td>
<td>8 days</td>
</tr>
<tr>
<td>Biological water</td>
<td>several hours</td>
</tr>
</tbody>
</table>

Flow resource (renewable)

GLOBAL ANNUAL WATER FLOWS

- **Precipitation** on land: 100’000 km³ / year
- **Unproductive evaporation** on land: 23’000 km³ / year
- Available water (runoff & transpiration): 77’000 km³ / year (Alcamo et al 2003)
  - **Transpiration** (plants): 40’000 km³ / year (Rost et al. 2008)
    - In crops 6’000 km³ / year
  - **Runoff**: 35’000 km³ / year (Rost et al. 2008)
- **Human water use**: 3’600 km³ / year (Alcamo et al 2003)
- **Irrigation** water consumption: 1’000-2’000 km³ / year

Adapted from Aveny GmbH
Global water scarcity

- Runoff: 35,000 km³/year (Rost et al. 2008)
- Suggested safe operational limit: 4000 km³/year (Rockström et al. Nature 2009)

Biodiversity loss

Nitrogen Cycle

BUT: Distribution problem!
Relevance of location

Unit: cm/year

High: 676
Low: 0

Source: Mitchell et al. 2003
PRECIPITATION VARIABILITY (TEMPORAL DISTRIBUTION)

Coefficient of Variation (STD/mean) of monthly precipitation

Source: Pfister et al. 2009
Intensity of water use somewhat related to population

Source: Center for International Earth Science Information Network, Columbia University, "Grided Population of the World"
FUTURE PRECIPITATION

Different model predictions for IPCC’s A1B scenario (different model runs)

Globally increased precipitation

Source: IPCC 2007
SPATIAL DISTRIBUTION OF CHANGE IN PRECIPITATION BY 2090

• A1B scenario (IPCC 2007)

Source: IPCC 2007
CLIMATE CHANGE - UNCERTAINTIES

• Temperature induced yield changes by 2050: Roughly 20% yield losses

• Changed irrigation demand (usually neglected)

W Schlenker and D B Lobell
**FUTURE CONSUMPTION AND PRODUCTION**

\[ I = P \times A \times T \]

- Impact
- Demand side
- Supply side

- **Impact**
  - Water use impact (l)

- **Population**
  - Population (cap)

- **Affluence**
  - Food consumption (kg food/cap)

- **Technology**
  - Water impact (l/kg food)

Adapted from Suh 2011
PROJECTED POPULATION CHANGE BY REGION, 2005-2050

(POPULATION INCREASE/DECREASE IN BILLIONS)

FUTURE CONSUMPTION AND PRODUCTION

Impact  
Demand side  
Supply side

\[ I = P \times A \times T \]

Affluence

Adapted from Suh 2011
Affluence:

E.G. Meat Consumption Per Capita

Data: 1960 - 2002 from FAO, China current from Liu and Savenije (2008), the rest is projection from Suh 2011
USA

Ecuador

Chad

Bhutan

Courtesy: Peter Menzel and Faith D’aluisio: Hungry planet: what the world eats

Adapted from Suh 2011
BIOFUEL PRODUCTION

• United States energy objectives

Adapted from Suh 2011
FUTURE CONSUMPTION AND PRODUCTION

Impact  Demand side  Supply side

\[ I = P \times A \times T \]

Adapted from Suh 2011
RELEVANT INDUSTRIAL SECTORS

• Agricultural production
  – (~85% of total water consumption)

• Power production
  – Especially hydropower
  – Also thermal power

• Other industrial sectors
  – Feedstock efficiency
  – Power consumption
  – Water recycling / emissions
**AGRICULTURE: GREEN REVOLUTION?**

Water and fertilizer are key parameters

BIOPHYSICAL CONDITIONS

• Intensification
  • Yield gap (improvement potential)

• Expansion
  • Suitability for crop production
    • Soils
    • Climate
    • Proximity to existing cropland
  • Land availability
    • Other cropland
    • Pastures
    • Forests / natural areas

Suitability for rain-fed wheat

(Plate 29, GAEZ, 2002)
ADDITIONAL IRRIGATION WATER CONSUMPTION IN 2050

Strategies:

– Intensification & food waste reduction
  Irrigation: + 1125 km³/yr (64%)

– Expansion on pastures
  Irrigation: +169 km³/yr (10%)
**Water Stress Index in 2050**

**Water Stress Index (WSI):**
- <0.1
- 0.1 – 0.2
- 0.2 – 0.4
- 0.4 – 0.6
- 0.6 – 1

**Only climate change**

**Intensification**

**Expansion**
WATER AND LCA

WULCA Working Group and Framework
**Problems**

- Respiratory effects
- Photochem. oxydation
- Ozone layer depletion
- Ionizing radiation
- Toxic Impacts
- Global warming
- Water use
- Acidification
- Eutrophication
- Land use
- Biotic resource use
- Abiotic resource use

**Outputs**
- Pesticide
- Diesel
- Cu
- CO₂
- Phosphate

**Inputs**
- Irrigation
- Water
- Crude Oil
- Iron Ore

And hundreds more...

**Areas of protection**

- Human Health
- Ecosystem Quality
- Resources
UNEP/SETAC Framework for impacts from water use in LCA, published in Bayart et al. 2010
UNEP/SETAC Framework for impacts from water use in LCA, published in Bayart et al. 2010
Based on Kounina et al. 2012
(Adjusted from Quantis - do not re-use without prior permission)
WHAT ARE THE IMPACTS ASSOCIATED WITH WATER?

**Problems**
- Respiratory effects
- Photochem. oxydation
- Ozone layer depletion
- Ionizing radiation
- Toxic Impacts
- Global warming
- Water use
- Acidification
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- Iron Ore
- ... And hundreds more...

**Outputs**
- Pesticide
- Diesel
- Cu
- CO₂
- Phosphate
- ...

And hundreds more...
DISTINCTION IN WATER IMPACT MODELING

Causes:
- Consumption
- Degradation
- Pollution emission affecting water

Impacts:
- Water Footprint
  - Impacts on human health from lower water availability
  - Impacts on ecosystems from lower water availability
- Direct impacts from pollution*

Impacts on the water resource:
- Impacts from Water use

* From traditional LCA models including eutrophication, ecotoxicity, thermal, etc.
FROM INVENTORY, TO RISK, TO IMPACTS...

Inventory of water use and emissions

Water stress assessment (midpoint)

Impacts (damages or endpoint)

WATER FOOTPRINT

Pollution
- Pollution
- Toxicty
- Eutrophication

Resource Availability

Water Inputs
- Surface water
- Groundwater
- Turbine water

Water Outputs
- Thermally polluted water
- Water consumed

Human health
- [DALY / y]

Ecosystem quality
- [PDF-m²-y / y]

Resources
- [MJ / y]

Adjusted from Quantis (do not re-use without prior permission)
Water Availability

Impacts from water pollution

Water Footprint Assessment Profile

Ex: 100 m³ eq

Ionizing radiation
Eutrophisation
Toxicity
Land Use
Acidification
Water Availability + Impacts from water pollution

Water Footprint Profile

- Human Health
- Ecosystems
- Ressources
**WATER FOOTPRINT AS PART OF LCA**

Water Footprint impacts

Water Footprint Assessment Profile

- Human Health
- Ecosystems
- Resources

Impacts from water pollution

All other LCA impacts not related to water
Setting goals and scope
Water footprint accounting
Water footprint sustainability assessment
Water footprint response formulation

Goal and scope definition
Inventory analysis
Impact assessment
Interpretation

WFN framework
LCA framework
Generic framework steps

Phase 1
Setting goals and scope

Phase 2
Water footprint accounting
Quantitative indicators (blue, green and grey water footprint)

Phase 3
Water footprint sustainability assessment
Quantitative indicators (environmental impacts)

Phase 4
Water footprint response formulation

Source: Boulay, Vionnet et Hoekstra, 2013
ISO STANDARDISATION PROCESS

ISO 14046, Water footprint – Requirements and guidelines
DIS ISO 14046 WATER FOOTPRINT

REQUIREMENTS AND GUIDELINES


**Participants:**
15 – 30 Countries
35 – 80 experts
• Launch of the project:
  – 25+.Sep.2009: List of P and O participants

Meeting every 6 months since 2009

**Proposer & Secretariat:**
SNV, Swiss Association for Standardization
Barbara Mullis, barbara.mullis@snv.ch
(formerly Marcel Schulze)

**Convener:**
Sebastien Humbert, Quantis, Lausanne, Switzerland, sebastien.humbert@quantis-intl.com, +41-79-754-7566

**Co-convener:**
Nydia Suppen Reynaga, Centro de analisis de cyclo de vida y diseno sustentable, Mexico, nsuppen@centroacv.com.mx
WORKING MEETINGS
ISO 14046: IN SUMMARY

• “Water Footprint: Principles, Requirements and Guidelines”

• International standard for water footprinting
  – This International Standard specifies requirements and guidelines to assess and report water footprint based on LCA
    • Terminology
    • Important stages to consider
    • Consistency with carbon footprinting and other LCA impact categories
      – Scope, system boundary, etc.
  • Review/Validation
  • Reporting
• Began 2009, ends 2013/14
• Towards industry and practitioners

Standard development steps:
1- NP: New Proposal
2- WD: Working Draft
   (PWD = preliminary WD)
3- CD: Committee Draft
4- DIS: Draft International Standard
5- IS: International Standard
The proposed International Standard will deliver

**principles, requirements and guidelines**

for a water footprint metric of

**products, processes and organisations,**

based on the guidance of

**impact assessment** as given in ISO 14044.

It will define how the different types of water sources (for example ground, surface, lake, river, green, blue, gray, etc.) should be considered, how the different types of water releases should be considered, and how the local environmental conditions (dry areas, wet areas) should be treated.

For products, it will apply the life cycle approach and will be based on the same product system as specified in ISO 14040 and ISO 14044.

At the organisation level, it will consider the guidance given by ISO 14064 for greenhouse gases.

The standard will also address the

**communication issues linked to the water footprint**
DIS ISO 14046 WATER FOOTPRINT

Requirements and guidelines

  - (Stockholm, Sweden)
  - Title, Scope; Draft structure PWD
  - (Leon, Mexico)
  - Detailed sections PWD (Discussion on PWD1)
- 24-26.01.2011: Third working meeting
  - (Lausanne, Switzerland)
  - Finalization of draft PWD (Discussion on PWD2)
- 26.06-02.07.2011: Fourth working meeting
  - (Oslo, Norway)
  - Acceptance of NWIP as WD1
- 28.11-02.12.2011: Fifth working meeting
  - (Sao Paulo, Brazil)
  - Discussion on WD2, Acceptance to go for CD (TBC)
  - (Bangkok, Thailand)
  - Result for CD1 vote; Discussion on CD1
  - Decision to go for a CD2
  - (Padova, Italy)
  - Discussion on CD2
  - Decision to go for a DIS
  - (Gaborone, Botswana)
  - DIS vote rejected
  - Decision to go for DIS2

Vote passed from the Participating countries but was rejected by the Observer countries, often caused by misunderstanding of the DIS.
Clarifications were made to the DIS and DIS2 will be sent around for voting again.
DIS ISO 14046

**WATER FOOTPRINT - ACCEPTED CONCEPTS**

1- Should be life-cycle based

2- Could be “stand-alone” or part of a full Life Cycle Assessment

3- Results should include impact assessment (volumes not sufficient) and address regional issues

4- Both quantity and quality should be considered

5- Comprehensive impact assessment related to water (not only water use but all impacts related to water)

6- Can result in one or several indicators
• To provide examples of application to guide practitioners
• To give examples of different methodologies and how they fit within the standard
• The next meeting to be concentrated on this document (if DIS accepted)
• Examples are still welcome
TYPES OF WATER FOOTPRINT METRICS AND ASSESSMENTS
TYPES OF METRICS RELATED TO WATER

- Scarcity Indicators – ex: Pfister et al., Boulay et al (simplified version)
- Stress Indicator – ex: Boulay et al., Veolia method
- Quality indicators: Eutrophisation, ecotoxicity, acidification, etc.
- Endpoint Modeling: Human health, Ecosystems and Resources
TYPES OF WATER FOOTPRINTS

LCA

Water Footprint

Water Availability Footprint

Water Scarcity Footprint

Reduced water availability from consumption and degradation + direct pollution impacts

Reduced water availability from consumption and degradation

Reduced water availability from consumption
### Water Footprint Types as per DIS ISO 14046

<table>
<thead>
<tr>
<th><strong>Profile of midpoint indicators</strong></th>
<th>Water availability</th>
<th>Water degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDPOINT</td>
<td>- Water scarcity footprint OR - Water availability footprint</td>
<td>- Human toxicity - Ecotoxicity - Eutrophication - Acidification</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Human health</strong></th>
<th><strong>Ecosystems</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Human toxicity</td>
<td>- Malnutrition and/or water related diseases</td>
</tr>
<tr>
<td>Ecosystems</td>
<td>- Terrestrial ecosystems - Aquatic ecosystems</td>
</tr>
</tbody>
</table>

- "qualified" water footprint (ex: "degradation" WF, "scarcity" WF, etc)
- Water footprint
INVENTORY
**Freshwater Requirement for Food Production**

<table>
<thead>
<tr>
<th>Food type</th>
<th>m$^3$·kg$^{-1}$</th>
<th>m$^3$·1,000·kcal$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals</td>
<td>1.5</td>
<td>0.47</td>
</tr>
<tr>
<td>Starchy roots</td>
<td>0.7</td>
<td>0.78</td>
</tr>
<tr>
<td>Sugarcrops</td>
<td>0.15</td>
<td>0.49</td>
</tr>
<tr>
<td>Pulses</td>
<td>1.9</td>
<td>0.55</td>
</tr>
<tr>
<td>Oilcrops</td>
<td>2</td>
<td>0.73</td>
</tr>
<tr>
<td>Vegetable oils</td>
<td>2</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>Vegetables</strong></td>
<td><strong>0.5</strong></td>
<td><strong>2.07</strong></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.53</td>
</tr>
<tr>
<td>Used in paper</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Meat</strong></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td><strong>Dairy products</strong></td>
<td></td>
<td>&gt;6</td>
</tr>
</tbody>
</table>

Rockstrom, et al, 2007: PNAS
2,400 litres
100 gr of chocolate

[Hoekstra & Chapagain, 2008] Source WFN, 2012
[Hoekstra & Chapagain, 2008] Source WFN, 2012
WHAT DO THE NUMBERS MEAN?

- Total water consumption over the complete production chain
  - Includes
    - naturally available water from soil moisture / precipitation (green water)
    - irrigation and process water consumption (blue water).
    - Water consumption is consumptive water use: It is the water used but not returned to the watershed (mainly evaporation and product integration)

- Missing information:
  - Source of water (natural / irrigation)
  - Influence on water cycle (water scarcity)
  - Polluted water (degradative use)
  - Impact on environment
Example 1: Cup of coffee

- Waterfootprint.org
  - Virtual water: 140 litre/cup

- Regionalised calculations
  - Virtual water: 157 litre/cup
  - Irrigation water: 46 litre/cup
  - Scarcity weighted irrigation water: 6 litre/cup

Footprint = 4% of virtual water
Example 2: Cotton T-shirt

- Waterfootprint.org
  - Virtual water: 2700 litre/shirt

- Regionalised calculations
  - Virtual water: 3086 litre/shirt
  - Irrigation water: 1668 litre/shirt
  - Scarcity weighted irrigation water: 1193 l/shirt

Footprint = 44% of virtual water
THE WATER FOOTPRINT OF A COW

Food
► 1300 kg of grains
   (wheat, oats, barley, corn, dry peas, soybean, etc)
► 7200 kg of roughages
   (pasture, dry hay, silage, etc)

Water
► 24000 litres for drinking
► 7000 litres for servicing.

[Hoekstra & Chapagain, 2008]
15,500 litres
1 kg of beef

[Hoekstra & Chapagain, 2008]
WATER FOOTPRINT INVENTORY
WHERE IS REGIONALISATION IN ALL THAT???

1 m³ of Water in TUNISIA ≠ 1 m³ of Water in UK

WATER FOOTPRINT

Tunisian beef steak ≠ UK beef steak

WHAT ABOUT WATER QUALITY???
<table>
<thead>
<tr>
<th></th>
<th>Meat diet</th>
<th>Vegetarian diet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kcal/day</td>
<td>litre/day</td>
</tr>
<tr>
<td>Industrial</td>
<td>3400</td>
<td>3600</td>
</tr>
<tr>
<td>countries</td>
<td></td>
<td>3400</td>
</tr>
<tr>
<td>Developing</td>
<td>2700</td>
<td>2050</td>
</tr>
<tr>
<td>countries</td>
<td></td>
<td>2700</td>
</tr>
</tbody>
</table>

Source: WFN, 2012
VEGETARIANS ALL OVER THE PLACE?

Source: http://www.alaskannature.com/inuit2.jpg

Photo by substack under the Creative Commons Attribution License 2.0: http://m.flickr.com/#/photos/substack/3131586597/
A VOLUMETRIC INVENTORY IS INSUFFICIENT FOR ASSESSING A WATERFOOTPRINT BECAUSE RESULTS OF SUCH INVENTORY AND THE IMPACTS RELATED TO WATER ARE OFTEN NOT CORRELATED
**WATER FOOTPRINT INVENTORY**

**Useful definitions**

**Drainage basin:**
Area from which direct surface runoff from precipitation drains by gravity into a stream or other water body (ISO DIS 14046)

**Water Withdrawal:**
Anthropogenic removal of water from any water body or from any drainage basin, either permanently or temporarily (ISO DIS 14046)

**Water Consumption**
Water removed from but not returned to the same drainage basin (ISO DIS 14046)

**Elementary water flow**
Water entering the system being studied and that has been drawn from the environment, or water leaving the system being studied that is released into the environment (ISO DIS 14046)

**Technosphere water flow**
Water embedded in the system being studied and that has been drawn from the environment at some previous stage in the product system
Area from which direct surface runoff from precipitation drains by gravity into a stream or other water body (ISO DIS 14046)
### Water Footprint Inventory

#### Regionalized Inventory

<table>
<thead>
<tr>
<th>Type and quantity of water resources used;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitations, Surface water, Ground water, Fossil water, Brackish water, Sea water.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water Quality parameters (Physical, chemical, bacteriological, qualitative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH, TDS, SS, TN, E-coli count, Temperature, Color, Turbidity, Fe, ..........</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Forms of consumptive water use;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation, transpiration, integration in product, discharge to sea, discharge into another water basin.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Forms of non consumptive water use,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge to another water resource type within the same drainage basin, In stream use</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emissions to air water and soil where these are relevant;</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂, Vn, Radioactivity, N, P, K, Bacteriology</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water scarcity indices and any other data that may be relevant;</th>
</tr>
</thead>
</table>
**Process environment**

Unit process water inventory

**Product water content**

**Water supply flows**

**Technosphere flows**

**Input**

- Elementary flows
  - Surface water (V,Q)
  - Groundwater (V, Q)
  - Δ Soil moisture
  - Δ Precipitation
  - Seawater (V, Q)

- Ref. Soil moisture
- Ref. Precipitation
- Environmental reference flows

**Output**

- Elementary flows
  - Surface water (V, Q)
  - Groundwater (V, Q)
  - Δ Soil moisture
  - Δ Evapotranspiration
  - Seawater (V, Q)

- Ref. Soil moisture
- Ref. Evapotranspiration
- Environmental reference flows

**Technosphere flows**

Adapted from Pfister et al.
INVOLVED CHALLENGES (COMPARED TO CARBON FOOTPRINT)

• Increased complexity (time requirements for LCA)

• Regionalized inventory data

• Regional supply chains
  – Connected with socio-economic circumstances

• Uncertainties (inventory & impacts)
  – New problem: picking the wrong location

• Software implementation & applicability
  – So far no LCA software can handle regionalized LCA
UNIT PROCESS WATER FOOTPRINT INVENTORY

Specified location and time

Water consumed (evaporation, transpiration, product integration, discharge to another water body...)

Emissions to Air, water and Soil (N, P, K, SO2, Pesticides, radio-active material, heavy metals,.....)

Water withdrawn from drainage basin A
-Volume $V_{in}$
-Source Type
-Water Quality
-Water Category $i_{in}$

Unit Process

Water released to drainage basin A
-Volume $V_{out}$
-Source Type
-Water Quality
-Water Category $i_{out}$

Water Volume $V_{in}$

$>\$ Water Volume $V_{out}$

Quality of Water Category $i_{in}$

Quality of Water Category $i_{out}$

Degradative Water Use

Consumptive Water Use

Adapted from Boulay et al, (2011)
Quality assessments are more accurate with better data on water quality, but not all parameters are necessary (potential consistency problem).

Categories describe water input and output of a process.

Water category data are provided by Boulay et al. for most watersheds worldwide.

### Water Categories and Dij

<table>
<thead>
<tr>
<th>Contamination</th>
<th>i = 1</th>
<th>i = 2a</th>
<th>i = 2b</th>
<th>i = 2c</th>
</tr>
</thead>
<tbody>
<tr>
<td>low coliforms, low toxic</td>
<td>Excellent</td>
<td>Good</td>
<td>Average</td>
<td>Average - Tox</td>
</tr>
<tr>
<td>low coliform, medium toxic</td>
<td>Medium</td>
<td>coliform, medium toxic</td>
<td>Low</td>
<td>coliform, higher toxic</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>General parameters</td>
<td></td>
</tr>
<tr>
<td>Fecal coliforms</td>
<td>UFC/100ml</td>
</tr>
<tr>
<td>Microcystin-LR</td>
<td>mg/l</td>
</tr>
<tr>
<td>True color</td>
<td>Color unit (CU)</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>mg/l</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>mg/l</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand</td>
<td>mgO₂/l</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>mg N/L</td>
</tr>
</tbody>
</table>
**ECOINVENT 3**

- Focus on industrial processes incl. transport and energy
  - Only physical water flows are recorded
    - Water input from sea, surface water, groundwater and from air (precipitation)
    - Water output to sea, to surface and ground water and to air (evaporation)
    - Product integration (inputs and outputs)
  - Quality issues are addressed by emission to water and resource use from water
  - Regional information attached as shapefile information
    - So far not beyond country level
Water Footprint Inventory Example

The Water footprint of Swiss Pizza
Inventory issues in regionalization and allocation
Pizza Margherita, the Swiss case

Main Ingredients

Tomato, vegetables (raw crops)

Wheat flour, olive oil (processed crops)

Mozarella, ham, mortadella (animal products)

Adapted from Eymann (2010)
Origin of Tomatoes

Analysis Of Swiss trade

- Switzerland (A%)
- Morocco (B%)
- Spain (C%)
- France (D%)
- Italy (E%)
- Netherlands (F%)
- Belgium (G%)
- Rest of the world (H%)

Adapted from Eymann (2010)
Irrigation water consumption of tomato supply mix in Switzerland

Weighted average water consumption:

\[ = 6.8 \times B\% + 3.1 \times C\% + 2.5 \times E\% + 2.5 \times A\% + 1.2 \times (D\% + F\% + G\% + H\%) \text{ m}^3/\text{t} \]

Adapted from Eymann (2010)
WATER FOOTPRINT INVENTORY
Comparative Irrigation water consumption for wheat supply in Switzerland

Adapted from Eymann (2010)
Water Footprint Inventory

Flour production

Wheat (harvested whole grains)

Ca. 90% economic value
Ca. 80% product fraction

Flour

Husks

Adapted from Eymann (2010)
**WATER FOOTPRINT INVENTORY**

Irrigation water allocation to flour

Average Irrigation water consumption: 235 $m^3 / t \text{ Wheat}$

Product fraction flour: 0.79 $t \text{ Flour} / t \text{ Wheat}$

Value fraction flour: 0.89

Allocated irrigation flour:

$$\frac{235 \ m^3 / t \text{ Wheat}}{0.79 \ t \text{ Flour} / t \text{ Wheat}} \times 0.89 = 264 \ m^3 / t \text{ Wheat}$$

Adapted from Eymann (2010)
WATER FOOTPRINT INVENTORY

Animal Products

Adapted from Eymann (2010)
WATER FOOTPRINT INVENTORY

- Maize: 22 t/Cow, 79 m³/t
- Grassilage: 20 t/Cow, 16 m³/t
- Hay: 4.6 t/Cow, 40 m³/t
- Others: 8.4 t/cow, 54 m³/ton
- Drinking water: 146 m³/Cow

2842 m³/Cow

Adapted from Eymann (2010)
2842 m³/Cow

6 Calves
1736 m³/t

Cow (meat)
618 m³/t

25 Tons milk
190 m³/t

Whey
54 m³/t

Mozzarella
1377 m³/t

Adapted from Eymann (2010)
Ingredients contribution to water consumption of Swiss Pizza

WATER FOOTPRINT INVENTORY

Adapted from Eymann (2010)
Data base development
**Water Footprint Inventory**

Data base development

- **Ecoinvent (ecoinvent center 2007)**
  - Withdrawal, source, spatial differentiation
  - No release flow, no quality
  - Partially regionalized

- **ETH water data (ESD 2012)**
- **Gabi (PE 2010):**
  - Water input and output,
  - No quality, some background systems missing (ex: mining)
  - Partially regionalized

- **GEMStat:** Database for water quality
  - Regionalized

- **WaterStat (WFN 2012)**
  - Assesses the inventory of consumption and degradation of crops and products derived from crops, farm animals and animal products according to the method WFN (Hoekstra et al. 2011)
- **Quantis Water Database** (Vionnet et al. 2012): Complete sets of inventory flows based on ecoinvent
  - Partially regionalized
Water Footprint Inventory

Data base development

Ecoinvent 3

• Only physical water flows are recorded
  – Water input from sea, surface water, groundwater and from air (precipitation)
  – Water output to sea, to surface and ground water and to air (evaporation)
  – Product integration (inputs and outputs)

• Quality issues are addressed by emission to water and resource use from water

• Regional information attached as shapefile information
  – So far not beyond country level
Regionalization challenges

- Increased complexity (time requirements for LCA)
- Regionalized inventory data
- Regional supply chains
  - Connected with socio-economic circumstances
- Uncertainties (inventory & impacts)
  - New problem: picking the wrong location
- Software implementation & applicability
  - So far no LCA software can handle regionalized LCA
Uncertainties

- Uncertainty
  - Inventory
  - Impact assessment
  - Spatial

- Variability
  - Technology
  - Climate
    - Regional
    - Temporal

Any LCA
Regionalized LCA

Adds to uncertainty of LCA using spatially aggregated inputs
Water Footprint Inventory

Towards impact assessment

All water resources

Vapor

Sea water

Fresh water

Liquid

Solid (ice)

Regionalized Water Inventory

Blue water type & quantity

Green water (rain / soil moisture)

Water scarcity & Quality

Pollutants Emissions To water, soil, air

Next stage

Water Footprint Impact Assessment
IMPACT ASSESSMENT METHODS
METHOD OVERVIEW

• Water indices and midpoint assessments
  – Water indices
  – Water availability assessment – methods
  – Midpoint impact category assessment methods
  – Examples

• Endpoint assessment
  – Human health
  – Ecosystems
  – Resource depletion
WATER SCARCITY INDEXES AND MIDPOINT ASSESSMENT
**WATER SCARCITY INDEXES**

- Based on withdrawal or consumption of water and availability

- Include or not human minimum requirement, ecosystems requirements, human development level

Methods or water index addressing water use
Methods addressing water pollution additionally to water use
Water index *human health* oriented addressing water use
Water index *ecosystem quality* oriented addressing water use

---

Kounina et al. 2012
USE-TO-AVAILABILITY RATIO (CRITICALITY RATIO)

Water Scarcity Index

Source: T Oki, S Kanae (2006)
USE-TO-AVAILABILITY RATIO (CRITICALITY RATIO)

On watershed level: Calibration, upstream/downstream

Source: Alcamo et al. 2000
ENVIRONMENTAL WATER SCARCITY

• Includes river flow requirements of ecosystem

Source: Smakthin et al. 2004
IWMl: Economic Water Scarcity

- Includes lack of infrastructure

*Projected Water Scarcity in 2025*

Source: IWMl 2007
FALKENMARK INDEX

- Water availability per person (Threshold 1700 m$^3$/cap·yr)

Global water scarcity - 2030

62%* of world population

Data from Fischer and Heilig (1997)
WATER AVAILABILITY ASSESSMENTS

Midpoint

Single indicators
- Frischknecht
- Pfister
- Boulay (simpl.)
- Veolia
- Hoekstra
- Boulay

Category indicators

Human health
- Bayart
- Humantox

Ecosystem quality
- Mila-I-Canals
- Ecotoxicity
- Acidification
- Eutrophication

Resources
- Mila-I-Canals

Endpoint

Human health
- Pfister
- Motoshita a
- Motoshita b
- Boulay
- Humantox

Ecosystem quality
- Pfister
- Hanafiah
- Van Zelm
- Verones
- Ecotoxicity
- Acidification
- Eutrophication

Resources
- Pfister
- Boesch
AVAILABILITY ASSESSMENT

• Can be associated with a midpoint assessment in LCA
• Most methods are related to a water scarcity index
  – Withdrawal to availability ratios (Pfister et al. 2009; Ridoutt and Pfister 2010b; Frischknecht et al. 2006; Veolia 2011; Milà i Canals et al. 2009)
  – Consumption to availability ratios (Boulay et al. 2011; Hoekstra et al. 2011).

→ Are used as a Characterization Factor (CF) to assess impacts from:
  – Water withdrawal (Ridoutt and Pfister 2010b; Frischknecht et al. 2006; Veolia 2011),
  – Water consumption (Boulay et al. 2011; Pfister et al. 2009 Hoekstra et al. 2011; Milà i Canals et al. 2009)
  – Water Degradation (Hoekstra et al. 2011; Veolia 2010; Boulay et al. 2011).
**Swiss Ecoscarcity 06**  
*Frischknecht et al. 2008*

Water use (Total water withdrawals except for hydropower)  
Distance-to-target approach

\[
\frac{\text{Water use}}{\text{Water availability}}^2 = \frac{\text{Water use}}{\text{Water availability}}^2
\]

**Critical value:** 20%

6 classes, 3 orders of magnitude

-> Used in biofuel LCA for tax exemption (official regulation) in Switzerland

<table>
<thead>
<tr>
<th>Water scarcity</th>
<th>UBP (points/m³ used)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>24</td>
</tr>
<tr>
<td>Moderate</td>
<td>220</td>
</tr>
<tr>
<td>Medium</td>
<td>880</td>
</tr>
<tr>
<td>High</td>
<td>2’400</td>
</tr>
<tr>
<td>Very high</td>
<td>6’200</td>
</tr>
<tr>
<td>Extreme</td>
<td>22’000</td>
</tr>
</tbody>
</table>

PFISTER ET AL 2009: WATER STRESS INDEX (WSI)

- Includes:
  - Withdrawal to availability (WTA)
  - Variability in precipitation (VF)
  - Flow regulation (highly regulated = SRF)

\[
WTA^* = \begin{cases} 
\sqrt{VF} \times WTA & \text{for SRF} \\
VF \times WTA & \text{for non-SRF}
\end{cases}
\]

- Index following logistic function:

\[
WSI = \frac{1}{1 + e^{-6.4 \cdot WTA^* \left( \frac{1}{0.01} - 1 \right)}}
\]
Pfister et al. 2009: WSI as Characterization/Weighting Factor

Water scarcity
The Water Impact Index accounts for...

... the reduction of water resources availability generated by a human activity. It allows evaluating how other water users (both humans and ecosystems) would potentially be deprived from this resource.

... expressed in “m$^3$ – Water Impact Index - equivalent”

Following parameters are finally considered:

- Volume of water used
  - Water abstracted
  - Water released
- Water quality
  - Water abstracted
  - Water released
- Local hydrological context
  - Freshwater scarcity
- Resource type

Bayart et al, LCM 2011
WATER IMPACT INDEX: MODEL

Water Impact Index = \( (W \times Q_w \times WSI_w) - (R \times Q_R \times WSI_R) \)

Volume of water withdrawn / discharged

Quality index

Water scarcity index

Veolia Environnement Recherche & Innovation

Bayart et al, LCM 2011
BOULAY ET AL: SCARCITY INDICATOR - COMPREHENSIVE

\[ \alpha^*_i = \frac{\text{Consumed water}_i}{\text{Available water}_i} \]

- **Surface water**
  - Excellent quality
  - Good quality
  - Medium quality
  - Etc...

- **Ground water**
  - Good quality
  - Medium quality
  - Etc...

- **General (if unknown)**

**Simplified:** assesses consumptive use only

**Comprehensive:** assesses degradative+consumptive use

1 Corrected for Seasonal variations

**SCARCITY INDICATOR - COMPREHENSIVE**

\[ \alpha_i^* = \frac{\text{Consumed water}_i}{\text{Available water}_i} \]

- Lower quality water is more abundant than higher quality water

*Boulay et al. (2011), ES&T 45(20): 8948–8957*
• $\alpha$ is modelled from $\alpha^*$
• Indicator between 0 and 1
• Based on accepted water stress thresholds:
  • Low $\rightarrow$ Set to 0
  • Medium S-Curve
  • high in between
  • very high $\rightarrow$ Set to 1

→ consumption of 1 m$^3$ of water will not affect other users when water is abundant
→ 1 m$^3$ of water consumed will eventually deprive other competing users of 1 m$^3$
Impact assessment

Water consumed (evaporation, product integration, ...)

$\text{CF is the availability indicator } \alpha$

Impact = $(\text{Volume}_{\text{in}} \times \text{CF}_{\text{in}}) - (\text{Volume}_{\text{out}} \times \text{CF}_{\text{out}})$

Note: CF = Characterization Factor

Boulay et al. (2011), ES&T 45(20): 8948–8957
QUALITY INTEGRATION FOR WATER FOOTPRINT AS STAND-ALONE INDICATOR

• Grey water: accounts for dilution volume of pollutants to comply with environmental standards
  – Chapagain et al. 2006

• Quality classes to account for water scarcity of different qualities
  – Boulay et al. 2011

• Apply also a water scarcity index to grey water if aggregated at all
  – Ridoutt and Pfister 2010

• Multiply a scarcity index by a quality index based on environmental regulations
  – Veolia Water Impact Index (under review)

• Calculate volume equivalents for water pollution by using endpoint impact assessment in LCA (see later for details)
  – Ridoutt and Pfister 2012
FROM INVENTORY, TO RISK, TO IMPACTS...

Inventory of water use

Water stress assessment

Impacts (damages)

WATER FOOTPRINT

Pollution

Resource Availability

Ecosystem quality

Human health

Resources

Adjusted from Quantis (do not re-use without prior permission)
**HUMAN TOXICITY**

**USEtox (ROSENBAUM ET AL. 2008)**

- **Description:** Quantifies the potential impact on human health from carcinogenic and non-carcinogenic diseases due to pollutant emissions to air, water and soil at the midpoint level. *For a Water Footprint, only the fate in water is considered.*
- **Unit:** Cumulative Toxic Units (CTU) for humans
- **Regionalization:** not regionalized by default, could be regionalized
- **Advantages:** more than 3’000 substances with complex cause-effect chain modeling (fate, exposure, intake effect), consensus method internationally recognized and published
- **Disadvantages:** Does not yet cover all range of substances, cannot be compared with other indicators affecting ecosystem quality (only midpoint level), it is a consensus and therefore simplified compared to other models
- **Alternative Methods:** ReCiPe *(Huijbregts and van Zelm 2009)*
**AQUATIC ACIDIFICATION**

**CML 2001 (NOT RECOMMENDED)**

- **Description:** Estimates the acidification potential and critical load of the ecosystem
- **Unit:** kg H⁺-equivalent
- **Regionalization:** not operationalized in CML 2001
- **Advantages:** LCA impact indicator with user experience
- **Disadvantages:** Not recommended by JRC and further developments needed (ongoing)
- **Alternative Methods:** EDIP97 (Wenzel et al. 1997)
Freshwater Eutrophication
ReCiPe (Goedkoop et al. 2008)

- **Description:** Quantifies the decrease of freshwater aquatic biodiversity from eutrophication from nutrients emissions into air, water and soil.
- **Unit:** kg Phosphorous-equivalent (kg N-equivalents for marine eutrophication)
- **Regionalization:** not regionalized, could be regionalized
- **Advantages:** Well-established LCA impact indicator
- **Disadvantages:** Eutrophication potential depends on the ecosystem type and location of emission and should be regionalized (here only global average), addressing both fate and effect aspects
**ECOTOXICITY**
**USEtox (ROSENBAUM ET AL. 2008)**

- **Description:** Quantifies the potential impact on ecosystems due to pollutant emissions to air, water and soil at the midpoint level.
- **Unit:** Cumulative Toxic Units (CTU) for test species
- **Regionalization:** not regionalized by default, could be regionalized
- **Advantages:** more than 3’000 substances with complex cause-effect chain modeling (fate, exposure, intake effect), consensus method internationally recognized and published, can distinguish impacts on aquatic and terrestrial ecosystems
- **Disadvantages:** Does not yet cover all range of substances, cannot be compared with other indicators affecting ecosystem quality (only midpoint level), it is a consensus and therefore simplified compared to other models
- **Alternative Methods:** ReCiPe (Huijbregts and van Zelm 2009)
Water Footprint at the midpoint

EXAMPLES
Various European countries and India

Spain

France

France

**Methodology Overview - Midpoint**

### Water Footprint Profile at Midpoint: Water Availability and Water Degradation

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Availability</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Scarcity</td>
</tr>
<tr>
<td>1</td>
<td>Pfister et al.</td>
</tr>
<tr>
<td>1</td>
<td>Boulay et al.</td>
</tr>
<tr>
<td>1</td>
<td>Swiss Eco-Scarcity</td>
</tr>
<tr>
<td>1</td>
<td>WFN, Hoekstra et al.</td>
</tr>
<tr>
<td>1a</td>
<td>Availability</td>
</tr>
<tr>
<td>1a</td>
<td>Boulay et al.</td>
</tr>
<tr>
<td>1a</td>
<td>Veolia Impact Index, Bayart et al.</td>
</tr>
<tr>
<td><strong>Water Degradation</strong></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Eutrophication</td>
</tr>
<tr>
<td>2</td>
<td>ReCIPe</td>
</tr>
<tr>
<td>3</td>
<td>Acidification</td>
</tr>
<tr>
<td>3</td>
<td>Impact 2002+</td>
</tr>
<tr>
<td>4</td>
<td>Ecotoxicity</td>
</tr>
<tr>
<td>4</td>
<td>Usetox</td>
</tr>
<tr>
<td>5</td>
<td>Human Toxicity</td>
</tr>
<tr>
<td>5</td>
<td>Usetox</td>
</tr>
</tbody>
</table>

- Only one method needed

---

**Midpoint Water Footprint Profile**

- **Water Scarcity Indicators**

- **Water Degradation Indicators**

---

**Sensitivity Analysis**

- End-of-life: packaging
- End-of-life: product
- Use: heating energy and moving the drum
- Use: tap water
- Manufacturing
- Suppliers
### Scarcity vs Stress

<table>
<thead>
<tr>
<th>Scarcity</th>
<th>Stress</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good quality input water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient quality input water</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results in m3 equiv.

- End-of-life: packaging
- End-of-life: product
- Use: heating energy and moving the drum
- Use: tap water
- Manufacturing
- Suppliers

---

METHOD OVERVIEW

• Water indices and midpoint assessments
  – Water indices
  – Water availability assessment – methods
  – Midpoint impact category assessment methods
  – Examples

• Endpoint assessment
  – Human health
  – Ecosystems
  – Resource depletion
ENDPOINT ASSESSMENT (ENVIRONMENTAL IMPACTS)
LCIA METHODS FOR WATER USE

<table>
<thead>
<tr>
<th>Use Type</th>
<th>LCI</th>
<th>Midpoint</th>
<th>Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consumptive Use</td>
<td>Water Losses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Degradative Use</td>
<td>Water-Quality Decrease</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In-Stream Storage</td>
<td>Changed Flow Regime</td>
</tr>
</tbody>
</table>

WATER IMPACTS ENDPOINT MODELING

Midpoint

Single indicators
- Frischknecht
- Pfister
- Boulay (simpl.)
- Veolia
- Hoekstra

Category indicators
- Human health
  - Bayart
  - Humantox
- Ecosystem quality
  - Mila-I-Canals
  - Ecotoxicity
  - Acidification
  - Eutrophication
- Resources
  - Mila-I-Canals

Human Health

Ecosystems Quality

Resources

Endpoint

Human health
- Pfister
- Motoshita a
- Motoshita b
- Boulay
- Humantox

Category indicators
- Ecosystem quality
  - Pfister
  - Hanafiah
  - Van Zelm
  - Verones
  - Ecotoxicity
  - Acidification
  - Eutrophication
- Resources
  - Pfister
  - Boesch
Dependent on the level of human development and economic welfare

Water use ultimately leads to an aggregated impact on human health, generally expressed in disability-adjusted life years (DALY)

- Lack of freshwater for hygiene and ingestion (spread of communicable diseases) (Motoshita et al. 2010b; Boulay et al. 2011)
- Water shortages for irrigation resulting in malnutrition (Pfister et al. 2009; Motoshita et al. 2010a; Boulay et al. 2011)
- Water shortage for freshwater fisheries resulting in loss of productivity and food supply (Boulay et al. 2011).
Main pathway is malnutrition due to lack of freshwater and diminished agricultural yields

\[
\Delta HH_{\text{malnutrition,i}} = WSI_i \cdot WU_{\%\text{agriculture,i}} \cdot HDF_{\text{malnutrition,i}} \cdot \frac{WR_{\text{malnutrition}}}{DF_{\text{malnutrition}}} \cdot WU_{\text{consumptive,i}}
\]

- \(HH_{\text{malnutrition,i}}\): human health damage (DALY)
- \(WSI\): physical water stress index (-)
- \(WU_{\%\text{agriculture}}\): fraction of agricultural water use (-)
- \(WDF_i\): water deprivation factor (m3 deprived/m3 consumed)
- \(HDF_{\text{malnutrition,i}}\): human development factor (-)
- \(WR_{\text{malnutrition}}\): per-capita water requirement to prevent malnutrition (m3/yr*capita)
- \(EF_i\): effect factor (capita *yr/m3 deprived) \(\rightarrow\) Annual number of malnurished people per water quantity deprived
- \(DF_{\text{malnutrition}}\): damage factor (DALY/yr*capita) \(\rightarrow\) Damage caused by malnutrition
- \(WU_{\text{consumptive}}\): consumptive water use (m3)
- \(CF_{\text{malnutrition}}\): specific damage per unit of water consumed (DALY/m3 consumed)

Pfister et al. (2009): Impacts on Human Health

**Midpoint**
- Mila-I-Canals
- Mila-I-Canals
- Bayart

**Endpoint**
- Human health
- Ecosystem quality
- Resources

**Category indicators**
- Humantox
- Ecotoxicity
- Acidification
- Eutrophication

**Additional indicators**
- Verones

**Map**

**Legend**
- WU₆₅, agriculture [%]
- HDI
- MNₚₙ
- DFₙₚₙ
- DALY from malnutrition

**Graphs**
- WTA* vs. WSI
- DALYₘₚₙ, rate vs. HDI
- DALYₘₚₙ, rate vs. MNₚₙ
BOULAY ET AL 2011: IMPACTS ON HUMAN HEALTH

Water Use

Quality?

Where?
GNI of Country

Functional for which user?

$ DEPRIVATION

$ COMPENSATION

$$$$$

SCARCITY

User’s Distribution

Disease

Malnutrition

Years of life lost

Environmental Impacts

Modification of water availability

Moderate for which user?

Where?
GNI of Country

Functional for which user?

$ DEPRIVATION

$ COMPENSATION

$$$$$
BOULAY ET AL 2011: IMPACT ASSESSMENT

Water consumed (evaporation, product integration, ...)

Specific Characterization Factors in DALY/m³

-Volume $V_{in}$
-Source
-Quality
-$CF_{in}$

Water Category $i_{in}$

-Volume $V_{out}$
-Source
-Quality
-$CF_{out}$

Water Category $i_{out}$

Impact = $(Volume_{in} \times CF_{in}) - (Volume_{out} \times CF_{out})$

Note: CF = Characterization Factor
BOULAY ET AL: IMPACTS ON HUMAN HEALTH

Characterization Factors in Daly/m³ for average quality water
MOTOSHITA ET AL. 2010: HUMAN HEALTH DAMAGE

ASSESSMENT

Water withdrawal and consumption

- Agricultural use
  - Food production loss
- Domestic use
  - Availability loss to safe water

Food consumption

- Nutritional deficiency

Human health damage

- Undernourishment, Diarrhoea, Intestinal diseases

<Consideration of influential factors>

Economic adaptability

<Consideration of influential factors>

Climate, Nutritional gap, Medical treatment

Statistical modeling on country scale

Motoshita et al 2010a/b

Human health

Pfister
Motoshita a
Motoshita b
Boulay
Humantox

<Ripple effect>

International food trade
IMPORTANT NOTE

These methods are addressing the SAME impact pathways, hence they are redundant and a consensual method is needed.
**Human Toxicity**

**USEtox (Rosenbaum et al. 2008)**

- **Description:** Estimates the potential impact on human health from carcinogenic and non-carcinogenic effects due to emissions to air, water and soil at the endpoint.
- **Unit:** Disability-Adjusted Life Year (DALY) lost
- **Reference:** Rosenbaum et al. 2008
- **Regionalization:** not regionalized but could be regionalized
- **Advantages:** Method that assesses more than 3’000 substances with complex cause-effect chain modeling, consensus method internationally recognized and published
- **Disadvantages:** Not recommended by JRC. Does not cover all range of substances, no regionalized characterization factors are available.
- **Alternative:** ReCiPe (Huijbregts and van Zelm 2009)
WATER IMPACTS ENDPOINT MODELING

Midpoint

- Single indicators
  - Frischknecht
  - Pfister
  - Boulay (simpl.)
  - Veolia
  - Hoekstra

Category indicators

- Human health
  - Bayart
  - Human tox

- Ecosystem quality
  - Mila-I-Canals
  - Ecotoxicity
  - Acidification
  - Eutrophication

- Resources
  - Mila-I-Canals

Endpoint

- Human health
  - Pfister
  - Hanafiah
  - Van Zelm
  - Verones

- Motoshita a
- Motoshita b
- Boulay
- Humantox

- Resources
  - Pfister
  - Boesch

Backup technology

Socio-economic

Human Health

Ecosystems Quality

Resources
Ecosystems impact pathways
(adapted from Kounina et al. 2012)

Scopes of methods developed are complementary
1- Decrease of terrestrial biodiversity due to the reduction of freshwater availability (Pfister et al. 2009)

2- Disappearance of terrestrial plant species due to groundwater extraction and related lowering of the water table (van Zelm et al. 2010)

3- Effects of water consumption on freshwater fish species (Hanafiah et al. 2011)
1- Pfister et al. 2009: Impacts on Ecosystem Quality

Adverse effects on ecosystem services/functions and biodiversity

\[ \Delta EQ = CF_{EQ} \cdot WU_{\text{consumptive}} = NPP_{\text{wat-lim}} \cdot \frac{WU_{\text{consumptive}}}{P} \]

EQ: ecosystem quality damage (m^2*yr)
CF(EQ): ecosystem damage factor/potential (m^2*yr/m^3)
WU(consumptive): consumptive water use (m^3)
NPP(wat-lim): fraction of net primary production limited in growth by reduced precipitation/water availability (-)
\( \rightarrow \) water shortage vulnerability of ecosystem
PDF: potentially disappeared fraction (of vegetation)
P: precipitation (m/yr)
A*t: theoretical area-time equivalent needed to recover the amount of water consumed by natural precipitation

1- Pfister et al: Impacts on Ecosystem Quality
2- VAN ZELM ET AL: GROUNDWATER EXTRACTION

Extraction → Lowering water level → Damage to environment

Fate $A_i \frac{\Delta AG_i}{\Delta Q_i}$
Groundwater model based on MODFLOW

Effect $d\text{PNOF}_i/dAG_i$
Multiple regression curves (MOVE model)

- Potentially Not
- Occurring Fraction of Plant Species (PNOF)

$AG = \text{Average Groundwater level (m)}$
$Q = \text{Extraction rate (m}^3/\text{yr)}$
$D = \text{Damage (-)}$

Data available for the Netherlands
625 terrestrial plant species; 141 on red list
Endpoint level
• Reduced fish species as a function of reduced river flow (Q)

\[ CF_{wc,i} = FF_i \cdot EF_i = \frac{dQ_{mouth,i}}{dW_i} \cdot \left( \frac{dPDF_i}{dQ_{mouth,i}} \cdot V_i \right) \]

- \( W \) = water consumption
- \( PDF \) = potentially disappeared fraction of species
- \( V \) = river volume
IMPORTANT NOTE

These methods are NOT addressing the same impact pathways, hence they can be used in parallel.
WATER QUALITY METHODS

- 1- Heat emissions
- 2- Ecotoxicity
- 3- Acidification
- 4- Eutrophication
**Aim:** model impacts on aquatic biodiversity of cooling water discharges to a river

River water for cooling, ambient temperature

Used water to river, elevated temperature

Modelling of river water temperature and changes due to cooling water discharges

Fate

PDF m3 year / MJ heat released

Response function for temperature induced mortality
ECOTOXICITY
USEtox (ROSENBAUM ET AL. 2008)

- **Description:** Estimates the potential toxic impact on freshwater aquatic biodiversity from emissions to air, water and soil at the endpoint level.
- **Unit:** Potentially Disappeared Fraction of species on an area during a time (PDF m² yr)
- **Reference:** Rosenbaum et al. 2008
- **Regionalization:** not regionalized, could be regionalized
- **Advantages:** Method that assesses more than 3’000 substances with complex cause-effect chain modeling, consensus method internationally recognized and published.
- **Disadvantages:** Not recommended by JRC. Does not cover all range of substances, no regionalized characterization factors are available.
- **Alternative:** ReCiPe (Huijbregts and van Zelm 2009)
AQUATIC ACIDIFICATION
CML 2001 PLUS MIDPOINT-ENDPOINT CONVERSION (NOT RECOMMENDED)

• Description: Estimates the acidification potential and critical load of the ecosystem
• Unit: kg H⁺-equivalent (to be transposed to endpoint)
• Regionalization: not operationalized in CML 2001
• Advantages: LCA impact indicator with user experience
• Disadvantages: No endpoints. Not recommended by JRC and further developments needed (ongoing)
• Alternative Methods: EDIP97 (Wenzel et al. 1997)
**FRESHWATER EUTROPHICATION**

**ReCiPe (Goedkoop et al. 2008)**

- **Description**: Estimates the decrease of freshwater aquatic biodiversity from eutrophication from P emissions at the endpoint level.
- **Unit**: Potentially Disappeared Fraction of species in Volume during time (PDF m³yr).
- **Reference**: Goedkoop et al. 2008
- **Regionalization**: not regionalized
- **Advantages**: Well-established LCA impact indicator
- **Disadvantages**: Not recommended by JRC. Eutrophication potential depends on the ecosystem type and, soils and water quality and should be regionalized (not done).
Overuse of renewable water bodies depends on the water renewability rate
Quantify the impact on future freshwater availability

Methods:
→ Amount of energy needed by seawater desalination to compensate the fraction of present freshwater depletion (Pfister et al. 2009)
→ Exergy content of the freshwater resource (Boesch et al. 2007).
Pfister et al: Impacts on resource quantities

- Depletion of water stocks: overuse

\[
F_{\text{depletion},i} = \begin{cases} 
\frac{\text{WTA} - 1}{\text{WTA}} & \text{for } \text{WTA} > 1 \\
0 & \text{for } \text{WTA} \leq 1 
\end{cases}
\]

- Desalination as backup technology

\[
\Delta RD = F_{\text{depletion}} \cdot M_{\text{J\surplus}} \cdot W_{\text{U\consumptive}}
\]

IMPACTS ON RESOURCES

**EXERGY BASED RESOURCE INDICATOR**

**Exergy**
- Concept from the second law of thermodynamics describing ‘maximum useful work’ or ‘available energy’
- As resource indicator, exergy can be defined as available energy when bringing resources to their most common state in the environment
- Concept applicable to all kinds of resources

**Advantages of the exergy-based indicator**
- Consistent framework
- No value choices
- No assumptions on future availability needed (recovery, substitution)
- All resources can be assessed

**Potential energy of water and water mass is assessed**

*Resources and products in LCA database*

- **Resources**
  - Solar irradiation
    - Solar energy
  - Atmosphere
    - Components in air
    - Wind (kinetic energy)
  - Water bodies
    - Water mass
    - Potential energy
  - Solids
    - Minerals
    - Fossil fuels
    - Metal ores
    - Nuclear ores
    - Geothermal energy

*Boesch et al. (2007)*
There is no consensus yet on the use of these methods in this impact category, more research is needed
EXAMPLES

Water Footprint at the endpoint
Various European countries and India

Spain

France

France

Water footprint of a load of laundry

Suppliers

Manufacturing

Use

End-of-life

Energy

Water

Evaporation

# Methodology Overview - Endpoint

## Water Footprint profile at endpoint: Ecosystems and human health impacts

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Availability</strong></td>
<td></td>
</tr>
<tr>
<td>Human Health (DALY)</td>
<td>Pfister et al.</td>
</tr>
<tr>
<td>Ecosystems Quality (PDF<em>m2</em>yr)</td>
<td>Pfister et al.</td>
</tr>
<tr>
<td>Ecosystems Quality (PDF<em>m2</em>yr)</td>
<td>Hannafiah et al.</td>
</tr>
<tr>
<td>Ecosystems Quality (PDF<em>m2</em>yr)</td>
<td>Van Zelm et al.</td>
</tr>
<tr>
<td><strong>Water Degradation</strong></td>
<td></td>
</tr>
<tr>
<td>Ecosystems Quality (PDF<em>m2</em>yr)</td>
<td>Thermal pollution, Verones et al.</td>
</tr>
<tr>
<td>Ecosystems Quality (PDF<em>m2</em>yr)</td>
<td>Eutrophication, Goedkoop et al.</td>
</tr>
<tr>
<td>Ecosystems Quality (PDF<em>m2</em>yr)</td>
<td>Acidification, Impact 2002+</td>
</tr>
<tr>
<td>HH: Human Health (DALY)</td>
<td>Human Toxicity, Usetox</td>
</tr>
</tbody>
</table>

*Only one method needed*

Sensitivity analysis for water quality and trade effect

Human health water footprint indicators

End-of-life: packaging
End-of-life: product
Use: heating energy and moving the drum
Use: tap water
Manufacturing
Suppliers

Daily per load of laundry

Maximal difference between sub-watershed and country scarcity

DIFFERENCE BETWEEN COUNTRY SCALE SCARCITY VS WEIGHTED-AVERAGE SCARCITY FROM SUB-WATERSHEDS

Maximal difference between source-specified water scarcity and unspecified

Maximal difference between the annual scarcity and the wettest/driest month

Conclusions

• Temporal resolution is relevant
  – Mainly for foreground process (global picture does merely change)
  – Different cultivations have different seasons
    • Crop choice / plantation dates

• Annual average maps (sector-specific)
  – For background processes
  – Based on withdrawal/consumption for sectors
HOW TO DO
WATER FOOTPRINTING
**Steps (Based on ISO 14044)**

1. Define goal of the study
2. Define the system
   1. Functional unit (product or service)
   2. System boundaries (background processes to be included): generally as scope 3 carbon footprints
   3. Define what flows and corresponding impacts are addressed
3. Gather inventory data
   1. From databases and literature for background processes (supply chain)
   2. Real data for foreground process
4. Apply impact assessment methods to inventory and compare results of applying different methods
5. Perform sensitivity analysis and improve data situation for most relevant processes
6. Draw conclusions including uncertainties of the results
7. Get an independent review of the study and address raised issues
RESULTS FROM WATER FOOTPRINT STUDY

- LCA based water footprint is mainly useful for understanding the system and options for most effective improvement of the total system under study
- It quantifies and localizes potential environmental issues in the whole system over the life cycle
- It is difficult to use it for absolute comparison as done for EPD (environmental product declaration) as uncertainties are high and consistencies among studies is generally poor
- Product category rules (PCR) will contribute to address this problem
EXAMPLE

Aluminum industry

- Bauxite mining
- Alumina production
- Anode production
- Electrolysis
- Ingot casting

1000 kg of aluminum
Problems
- Respiratory effects
- Photochem. oxydation
- Ozone layer depletion
- Ionizing radiation
- Toxic Impacts
- Global warming
- Water use
- Acidification
- Eutrophication
- Land use
- Biotic resource use
- Abiotic resource use

Areas of protection
- Human Health
- Ecosystem Quality
- Resources

Outputs
- Pesticide
- Diesel
- Cu
- CO₂
- Phosphate
- ... 

Inputs
- Irrigation
- Water
- Crude Oil
- Iron Ore
- ...

And hundreds more...
CALCULATION FOR EACH PROCESS STEP
AND RESULTING WATER AVAILABILITY FOOTPRINT (WAF)

\[ \alpha = \text{stress CF} \]

\[ \text{WAF} = (12.9 \times 1) + (2.28 \times 7.8 \times 10^{-5}) - (10.2 \times 1) \]

- \( V = 12.9 \, \text{m}^3 \), \( \alpha = 1 \)
- \( V = 2.28 \, \text{m}^3 \), \( \alpha = 7.8 \times 10^{-5} \)
- \( V = 10.2 \, \text{m}^3 \), \( \alpha = 1 \)

\[ \text{WAF} = 2.72 \]
Calculation for each process step and resulting water availability footprint (WAF)

**Bauxite**
- V = 2.21 m³
- WAF = -0.29

**Alumina**
- V = 10.2 m³
- WAF = 2.72

**Anode**
- V = 0.4 m³
- WAF = 0.85

**Electrolysis**
- V = 4.7 m³
- WAF = 4.7

**Casting**
- V = 4.9 m³
- WAF = -1.08

WAF = 2.72 - 0.29 + 0.85 + 4.7 - 1.08 = 6.91 m³ eq.
Human Health
Ecosystem Quality
Resources

Problems
- Respiratory effects
- Photochem. oxydation
- Ozone layer depletion
- Ionizing radiation
- Toxic Impacts
- Global warming
- Water use
- Acidification
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Areas of protection
- Human Health
- Ecosystem Quality
- Resources

Outputs
- Pesticide
- Diesel
- Cu
- CO₂
- Phosphate

Inputs
- Irrigation
- Water
- Crude Oil
- Iron Ore

And hundreds more...
Impacts from pollution emissions:
Aquatic eutrophication, aquatic ecotoxicity, aquatic ionising radiation, aquatic thermal pollution and aquatic acidification, as well as other impacts influencing water recharge and filtration related to land use.

Impacts from resource availability
(e.g. Pfister et al. + Hannafiah et al. + Van Zelm et al.)

Impacts from resource availability
(e.g. Boulay et al., 2011)

Impacts from pollution emissions:
Ionising radiation and human toxicity
(only through aquatic routes of exposure)
### Water Footprint Framework

#### Groups of midpoint categories
- Global warming
- Land use
- Resource use
- Water use
- Acidification
- Eutrophication
- Ecotoxicity
- Respiratory effects
- Human toxicity
- Ozone layer depletion

#### Inputs
- Water well
- Arable land
- Crude oil
- Iron ore

#### Outputs
- Pesticide
- Particules
- Copper
- CO$_2$
- Phosphate

#### Damage or endpoint
- Resources & ecosystem services
- Ecosystem quality
- Human health

And hundreds more…

(WATER FOOTPRINT FRAMEWORK)

(Carbon footprint)

(Water Footprint)

(Additional reporting categories)
WATER FOOTPRINT AS PART OF AN LCA:
HUMAN HEALTH IMPACT CATEGORY

1000 kg primary aluminium

- Carbon footprint on human health
- Water footprint on human health
- Other impacts HH

Global warming, long term, human health DALY
Global warming, short term, human health DALY
Water withdrawal, human health DALY
Non-carcinogens, water intake DALY
Carcinogens, water intake DALY
Ionizing radiation DALY
Respiratory inorganics DALY
Photochemical Oxydant Formation DALY
Ozone Layer Depletion DALY
Non-carcinogens, indoor DALY
Non-carcinogens, no water intake DALY
Carcinogens, pesticide residues DALY
Carcinogens, indoor DALY
WATER FOOTPRINT AS PART OF AN LCA: ECOSYSTEM QUALITY IMPACT CATEGORY

Carbon footprint on ecosystem quality

Water footprint on EQ

Other impacts EQ

1000 kg primary aluminium

- Global warming, long term, ecosystem PDF.m2.yr
- Global warming, short term, ecosystem PDF.m2.yr
- Aquatic ecotoxicity PDF.m2.yr
- Water table lowering, terr. ecosystems PDF.m2.yr
- Water withdrawal, aquatic ecosystems PDF.m2.yr
- Thermally polluted water PDF.m2.yr
- Water withdrawal, terrestrial ecosystems PDF.m2.yr
- Water Stream Use and Management PDF.m2.yr
- Land occupation, biodiversity PDF.m2.yr
- Terrestrial acidification PDF.m2.yr

Water footprint as part of an LCA: ecosystem quality impact category
IMPACT ASSESSMENT METHODS

AVAILABILITY AND REFERENCES
– Midpoint and endpoint factors
  • compatible with Eco-indicator 99 (EI99)
– More than 11‘000 watersheds characterized (global coverage)
– Publicly available:

  [Google Earth layer]
  [http://www.ifu.ethz.ch/ESD/downloads/EI99plus]

– Monthly WSI factors (Pfister and Baumannn 2012):
BOULAY ET AL. 2011

• Impact Assessment method including quality aspects


Results and more data/tools

www.ciraig.org/wateruseimpacts
WFN Blue Water Scarcity

Spreadsheet and shapefile available online (for 405 watersheds);
Hoekstra et al. (2012)

www.waterfootprint.org (Covers also the data available from Mila I Canals et al. (2009))

Training material:
http://www.waterfootprint.org/?page=files/Presentations

Figure: Hoekstra et al. (2012)
OUTLOOK

• Quantis Water Database
• Ecoinvent 3
• IMPACT WORLD +
• SimaPro 8
QUESTIONS
References I


References II


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ACKNOWLEDGMENTS AND DISCLAIMER
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• It is difficult to use it for absolute comparison as done for **EPD** (environmental product declaration) as uncertainties are high and consistencies among studies is generally poor

• Product category rules (**PCR**) will contribute to address this problem
END OF MATERIAL

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ADDITIONAL MATERIAL
Authors of Training material

• **Stephan Pfister** is a senior research associate at ETH Zurich, focusing on the impact assessment of water consumption in Life cycle Assessment (LCA) of agriculture and power production and advancing water footprinting concepts including future assessments and international trade. For his PhD thesis he was honored by the "SETAC Europe LCA Young Scientist Award" and the “ETH Zurich Medal”. Stephan is member of the "ecoinvent Editorial Board" focusing on water data collection and associated editor for The International Journal of Life Cycle Assessment.

• **Anne-Marie Boulay** recently finished (2013) her PhD on development, comparison and applications of water use impact assessment methods in LCA at Ecole Polytechnique of Montreal, Canada. She is chairing the WULCA working group on water us in LCA, of the UNEP-SETAC Life Cycle Initiative and is participating as the Canadian representative to the ISO Water Footprinting (14046) standard development.
Water Footprint at the endpoint

EXAMPLES
Comparing indicators: Car case study

• Water footprinting in the automotive industry
  – How much water is consumed in a car’s life cycle?
  – What is the impact of this water consumption?

• Procedure
  – Determine water consumption on an inventory level by means of LCA software and Volkswagen’s LCI data bases
  – Geographical differentiation of water consumption according to Import mixes, location of production sites, etc.
  – Selection of methods for impact assessment & determination of regional characterization factors
  – Impact assessment
  – Interpretation

Berger et al. (2012)
Case study results

- 50 - 80 m³ freshwater consumption along the life cycle, less than 10 % consumed onsite
- Ranking of cars changes for different impact assessment, as water consumptions in different countries is assessed differently
- Damages resulting from water consumption relatively low (1-7% of total LCA damage)

Berger et al. (2012)
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