Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

WULCA
A LIFE CYCLE INITIATIVE PROJECT

LCA XIII– Orlando – Septembre 30th 2013

Anne-Marie Boulay and Stephan Pfister

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

WULCA

www.wulca-waterlca.org

Life Cycle Initiative

UNEP SETAC

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)

WULCA

www.wulca-waterlca.org

- 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

WULCA

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

www.wulca-waterlca.org

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?


Cotton for export
Former Aral Sea, Central Asia
Source

Endangered Indus River Dolphin

[Photo: WWF]

Source WFN, 2012

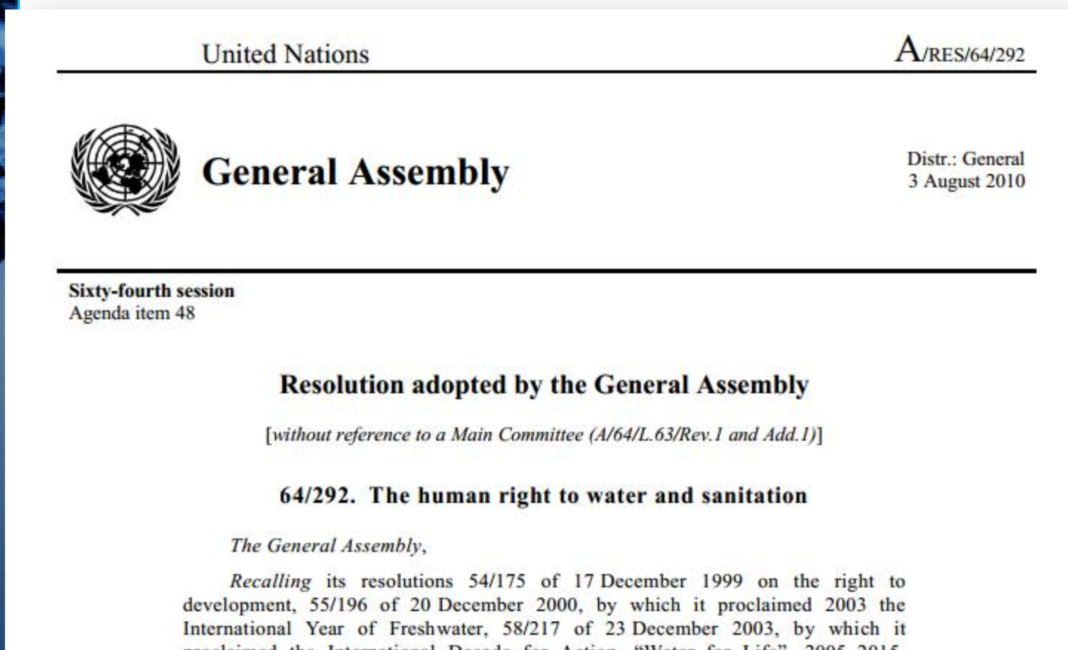
FN, 2012

Devecser, Hungary, Oct. 5, 2010

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



United Nations A/RES/64/292

General Assembly

Distr.: General
3 August 2010

Sixty-fourth session
Agenda item 48

Resolution adopted by the General Assembly

[*without reference to a Main Committee (A/64/L.63/Rev.1 and Add.1)*]

64/292. The human right to water and sanitation

The General Assembly,

Recalling its resolutions 54/175 of 17 December 1999 on the right to development, 55/196 of 20 December 2000, by which it proclaimed 2003 the International Year of Freshwater, 58/217 of 23 December 2003, by which it proclaimed the International Decade for Action, "Water for Life", 2005–2015,

Source: UN: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/64/292

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

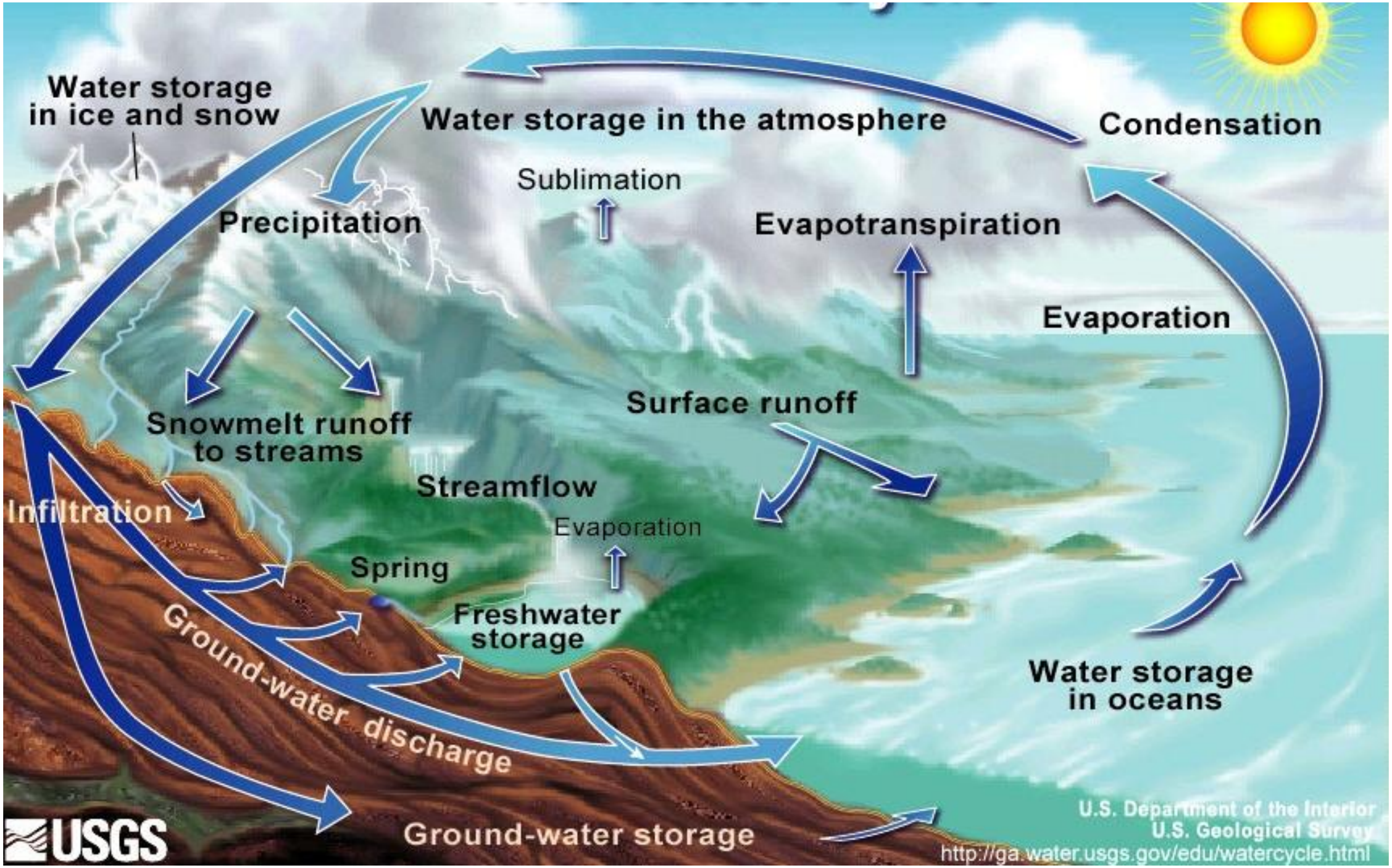
WATER FOOTPRINT – CONCEPTUAL AGREEMENTS

- 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

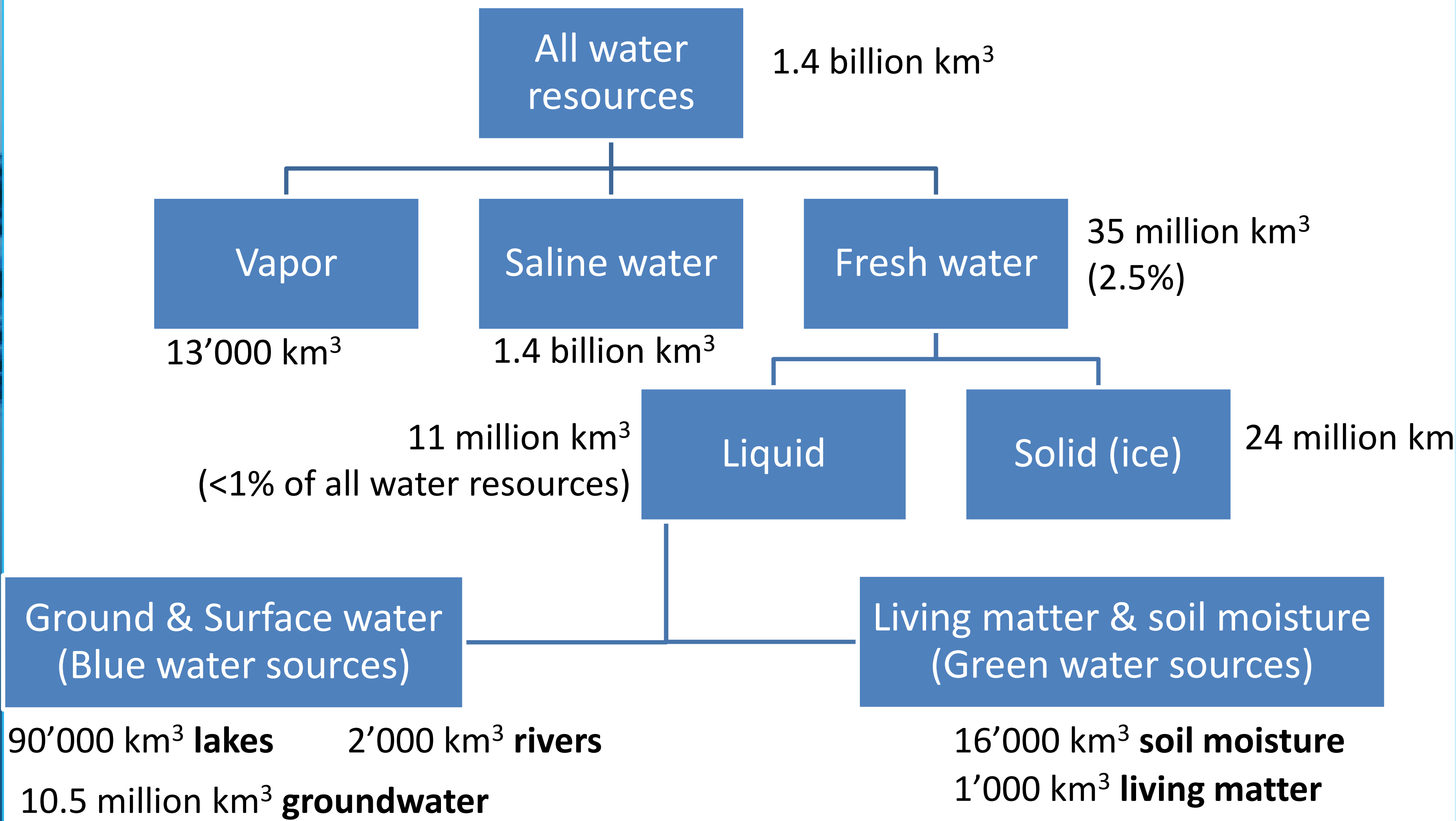
Natural cycle and man-made issues

The Water Cycle



Source: U.S. Department of the Interior | U.S. Geological Survey
URL: http://ga.water.usgs.gov/edu/watercycle.html

HYDROSPHERE - VOLUMES



Source: Shiklomanov and Rodda (2003) ISBN: 0 521 82085 5

Global Average Renewal Rates

Table 1.14. *Periods of renewal of water resources on the Earth*

Water of hydrosphere	Period of renewal
World Ocean	2 500 years
Ground water	1 400 years
Polar ice	9 700 years
Mountain glaciers	1 600 years
Ground ice of the permafrost zone	10 000 years
Lakes	17 years
Bogs	5 years
Soil moisture	1 year
Channel networks	16 days
Atmospheric moisture	8 days
Biological water	several hours

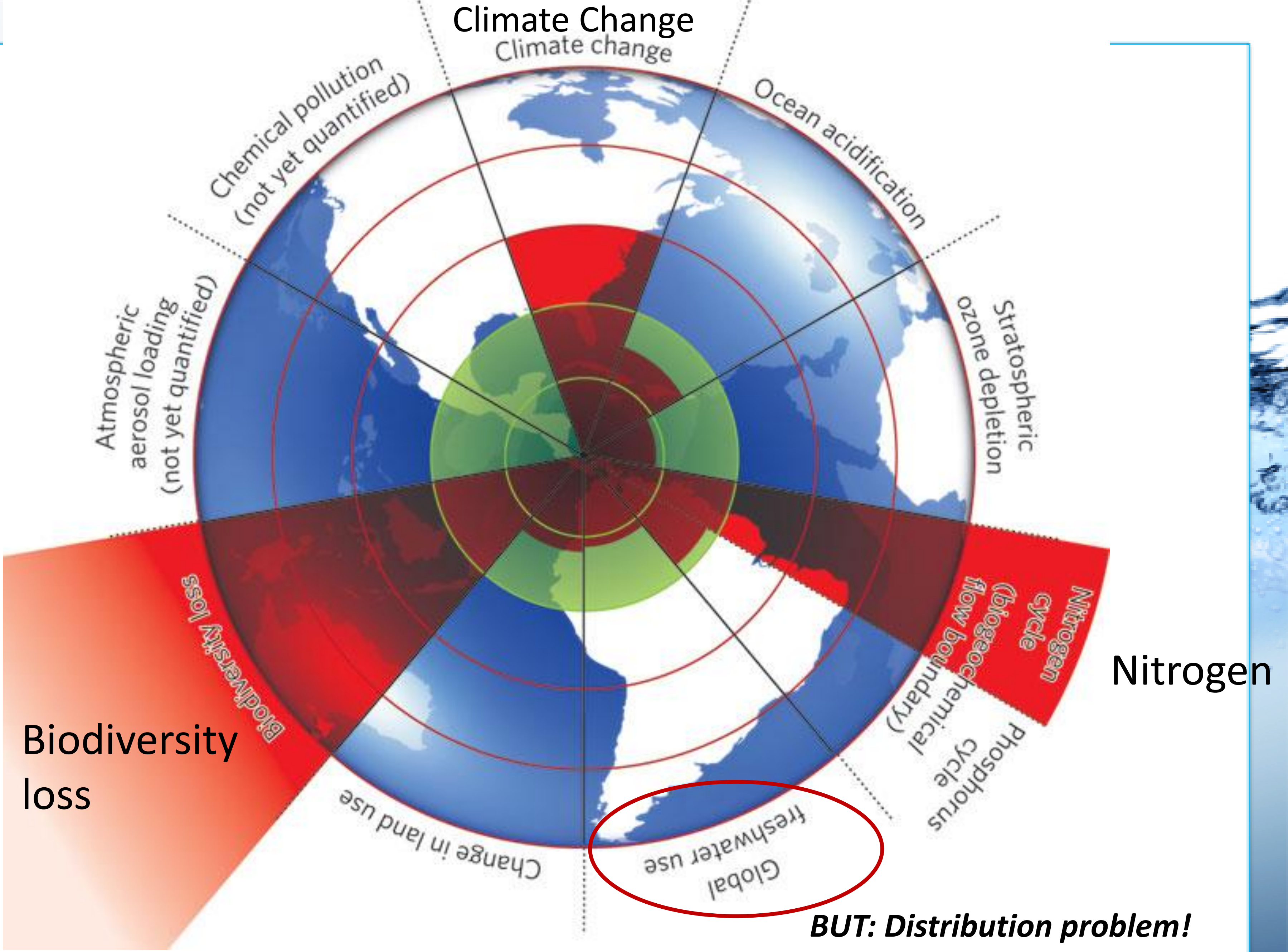
Flow resource (renewable)

Shiklomanov and Rodda (2003) ISBN: 0 521 82085 5

GLOBAL ANNUAL WATER FLOWS

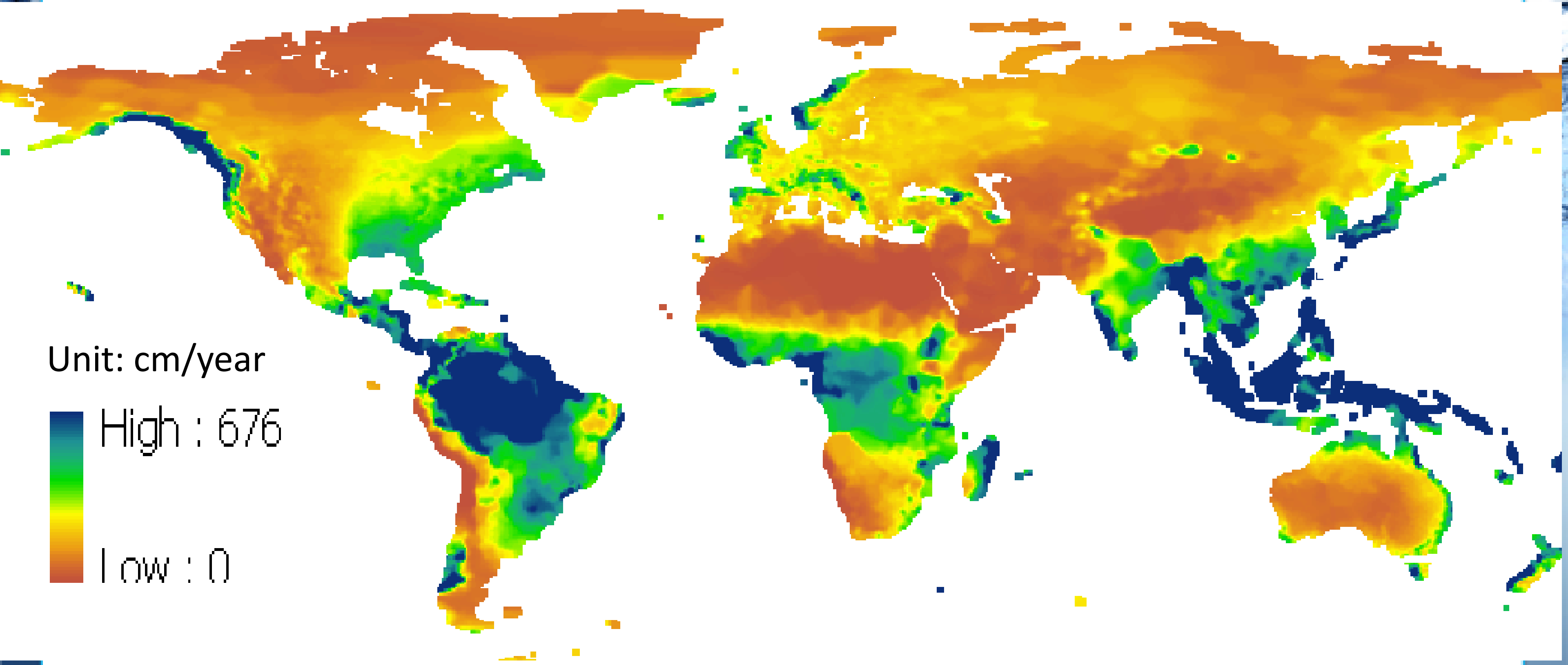
- **Precipitation** on land: **100’000** km^3 / year
- **Unproductive evaporation** on land: 23’000 km^3 / year
- Available water (**runoff & transpiration**): **77’000** km^3 / year (Alcamo et al 2003)
  - **Transpiration** (plants): **40’000** km^3 / year (Rost et al. 2008)
    - In crops 6’000 km^3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

Adapted from Aveny GmBH


Climate Change
Climate change
Ocean acidification
Stratospheric ozone depletion
Nitrogen cycle (biogeochemical flow boundary)
Phosphorus cycle
Nitrogen
Global freshwater use
Change in land use
Biodiversity loss
Biodiversity loss
Atmospheric aerosol loading (not yet quantified)
Chemical pollution (not yet quantified)
BUT: Distribution problem!

PRECIPITATION DISTRIBUTION

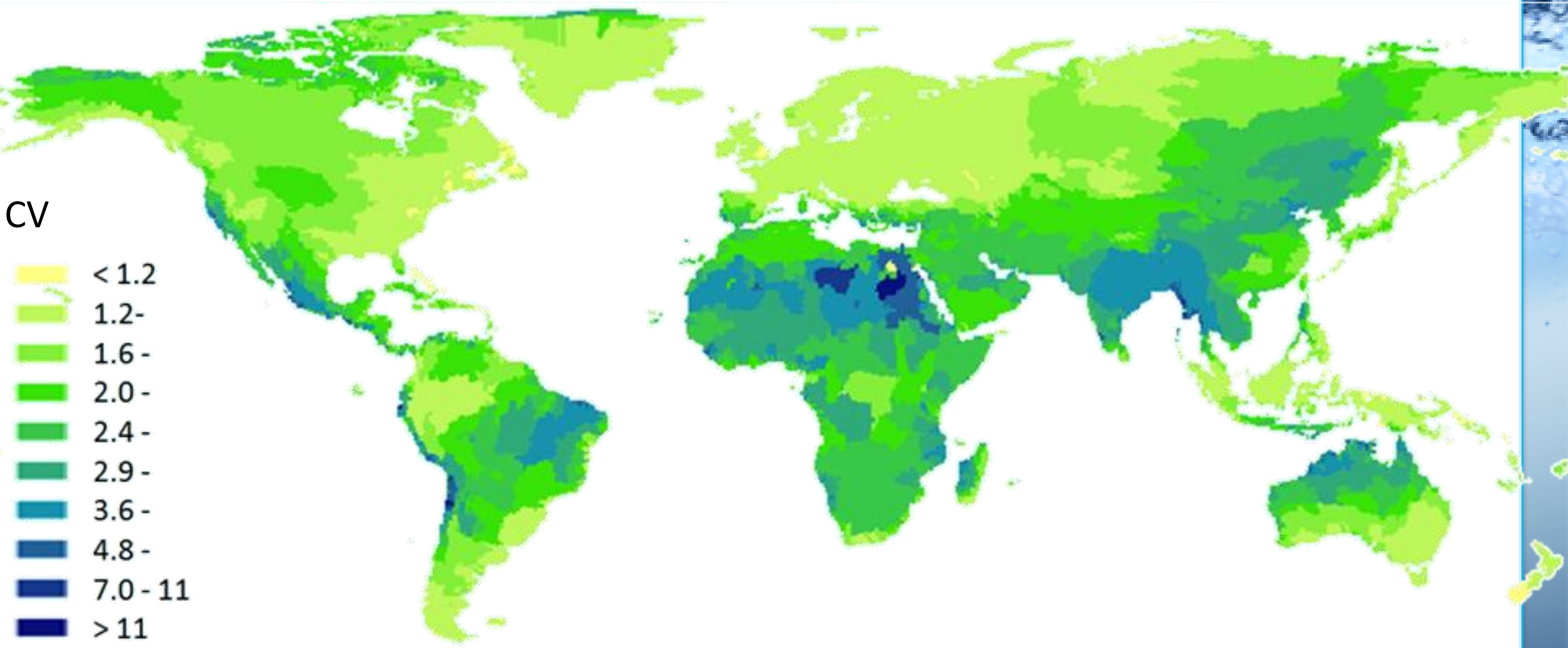
Relevance of location



Source: Mitchell et al. 2003

PRECIPITATION VARIABILITY (TEMPORAL DISTRIBUTION)

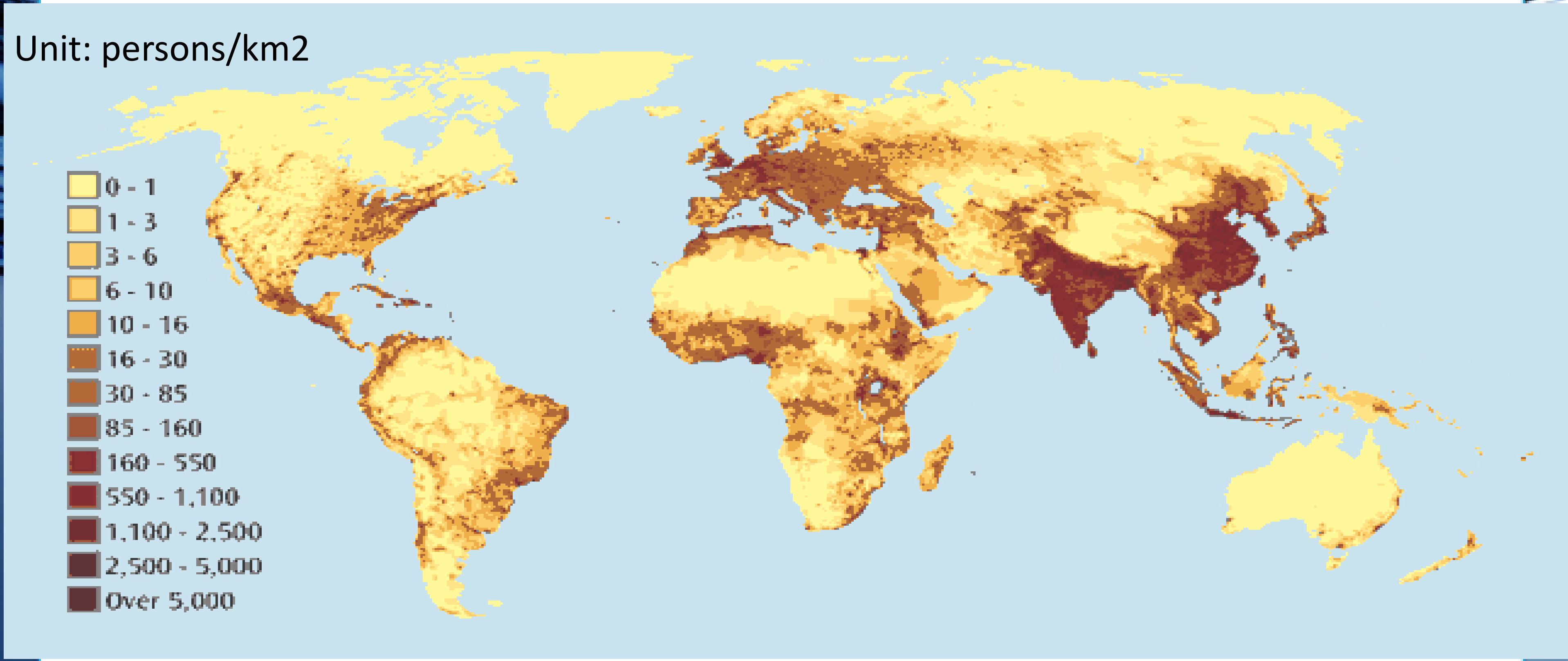
Coefficient of Variation (STD/mean) of monthly precipitation



Source: Pfister et al. 2009

POPULATION DENSITY

Intensity of water use somewhat related to population

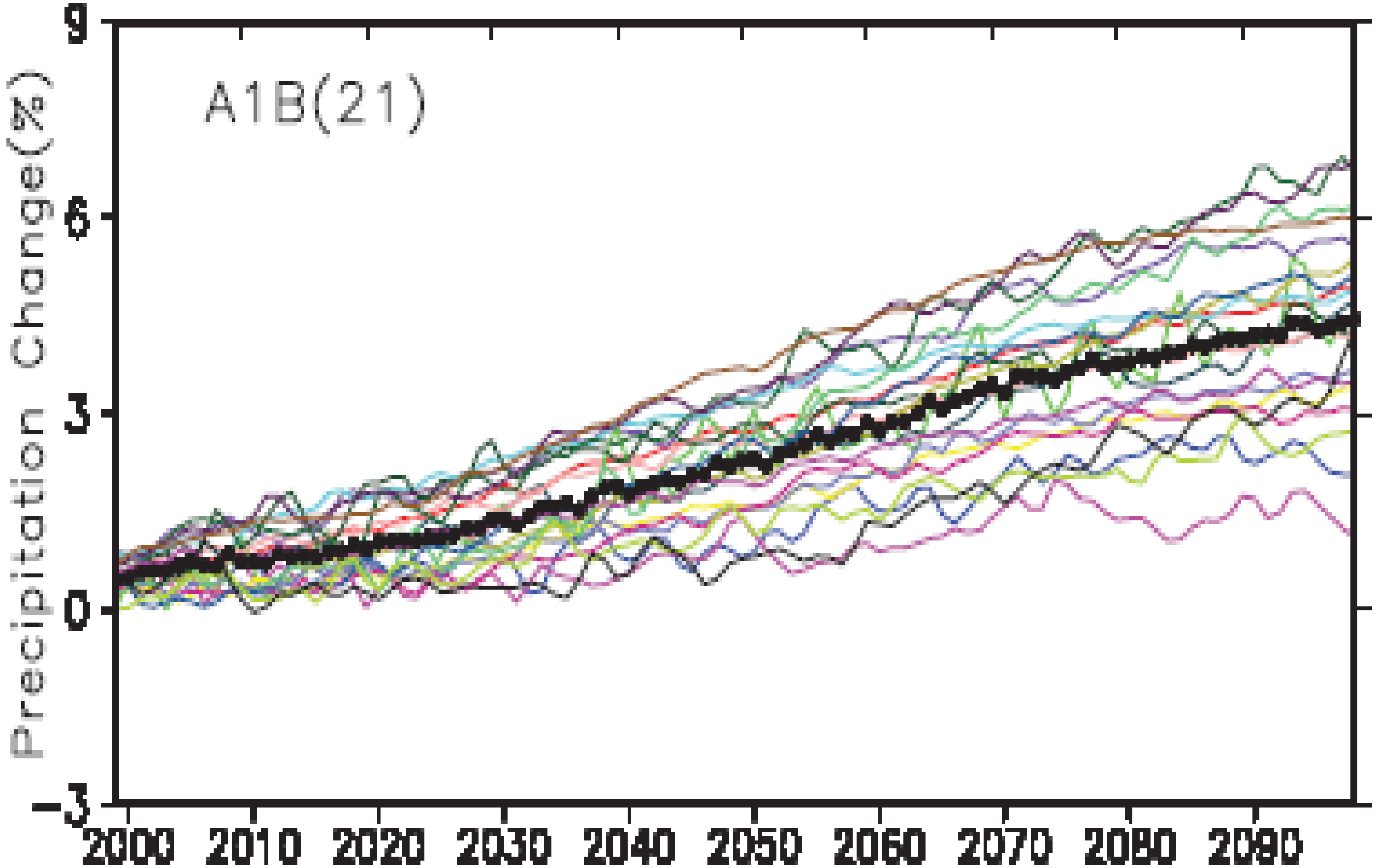


Source: Center for International Earth Science Information Network, Columbia University, "Grided Population of the World"

FUTURE PRECIPITATION

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

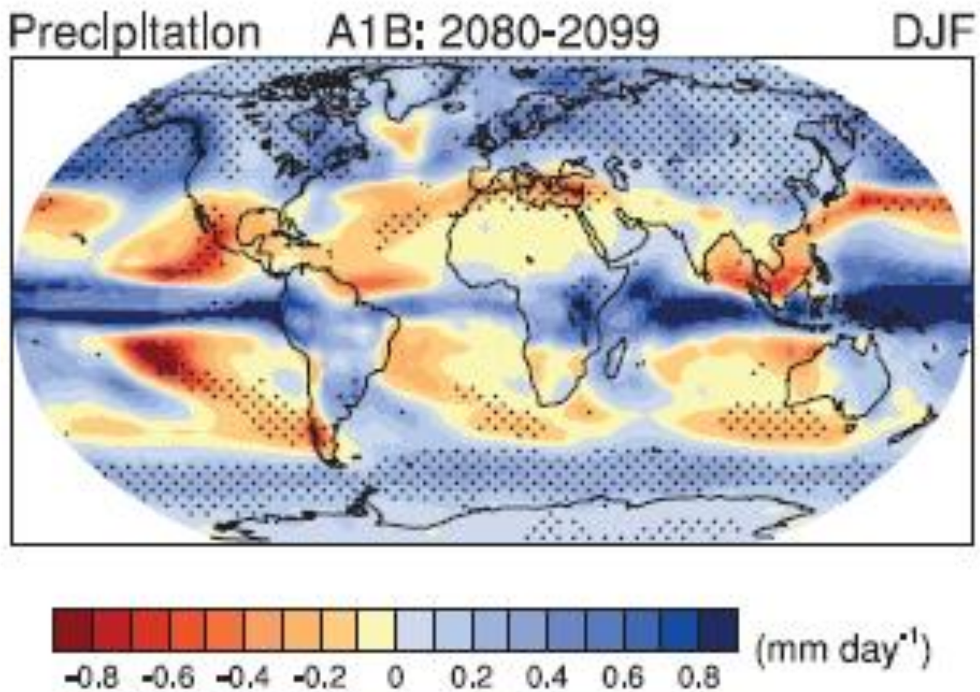
Globally increased precipitation



Source: IPCC 2007

SPATIAL DISTRIBUTION OF CHANGE IN PRECIPITATION BY 2090

- A1B scenario (IPCC 2007)



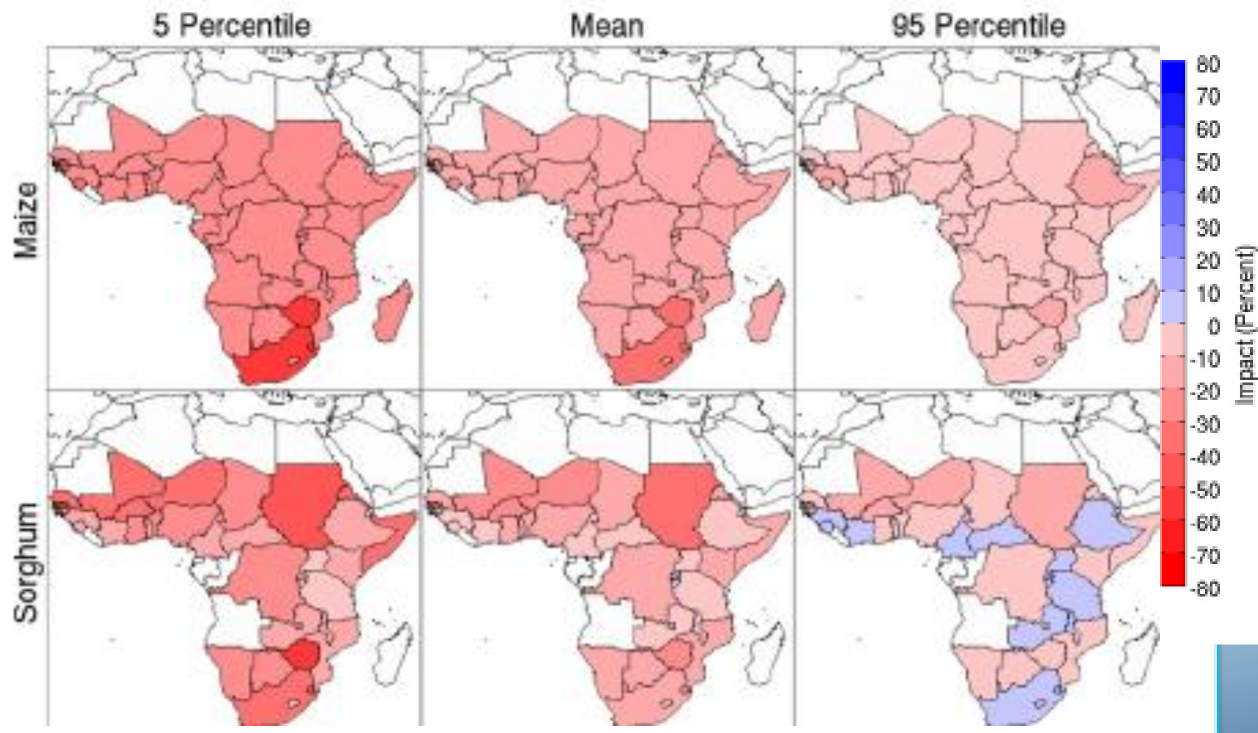
Less precipitation in many arid regions

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
Environ. Res. Lett. **5 (2010) 014010**

Future consumption and production

Impact | Demand side | Supply side

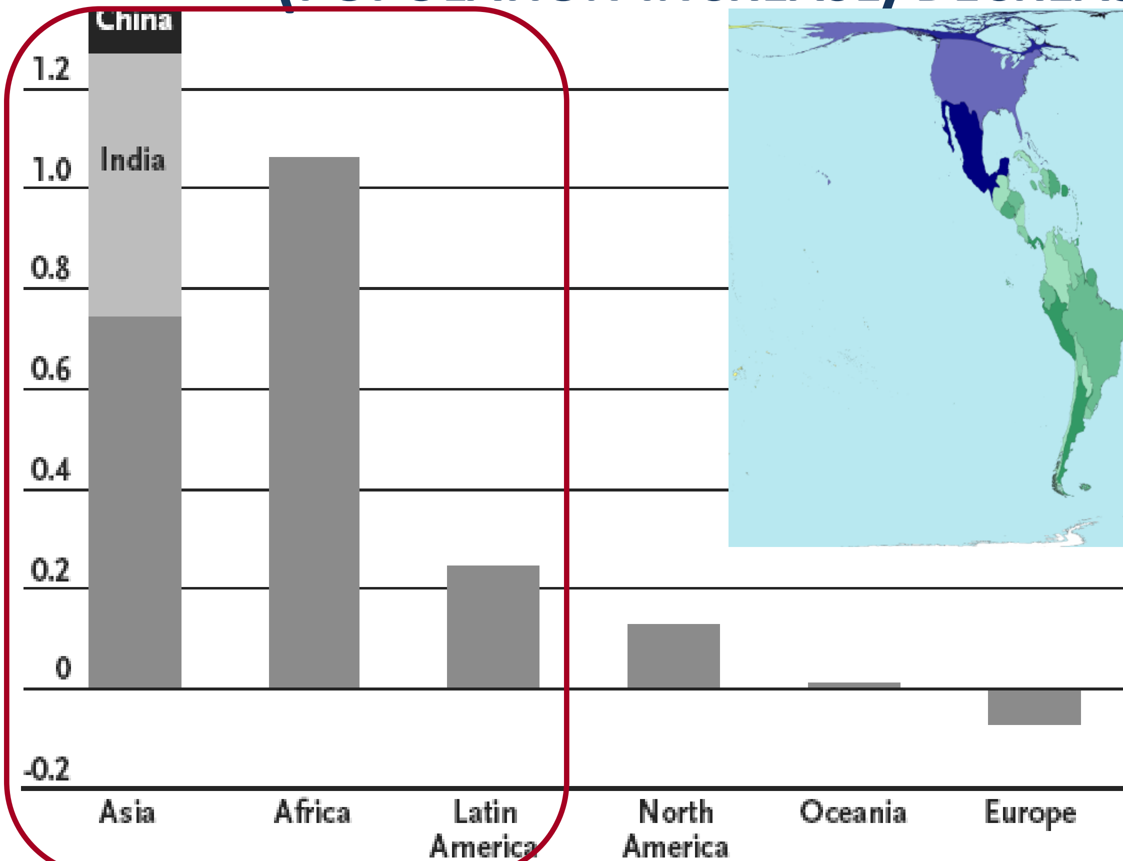
$$I = P * A * T$$

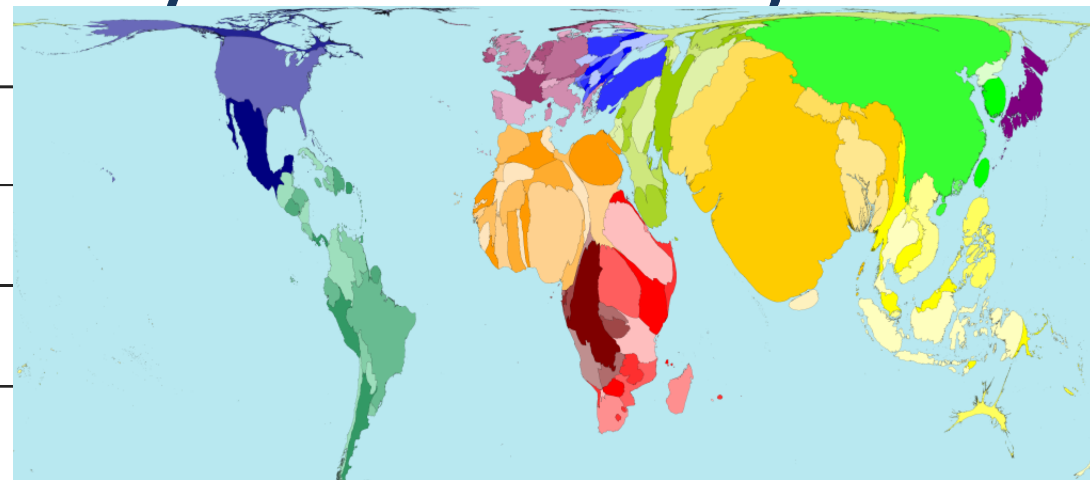
- Impact → Water use impact (l)
- Population → Population (cap)
- Affluence → Food consumption (kg food/cap)
- Technology → Water impact (l/kg food)

Adapted from Suh 2011

Projected Population Change by Region, 2005-2050

(Population increase/decrease in billions)





Adapted from Suh 2011

Source: Haub, C. 2005. World Population Data Sheet - 2005.

Future consumption and production

Impact | Demand side | Supply side

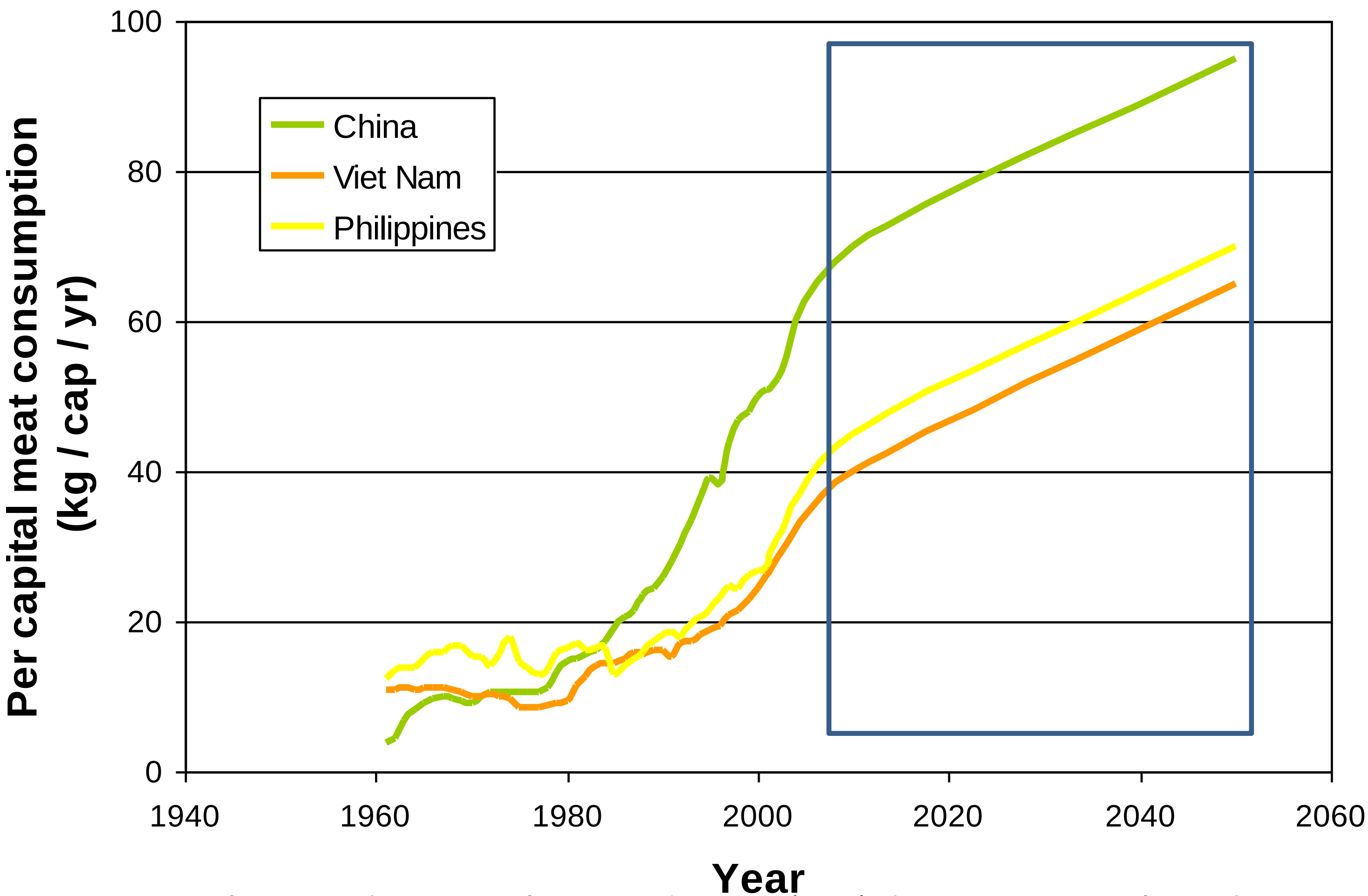
$$I = P*A*T$$

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

Chad

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

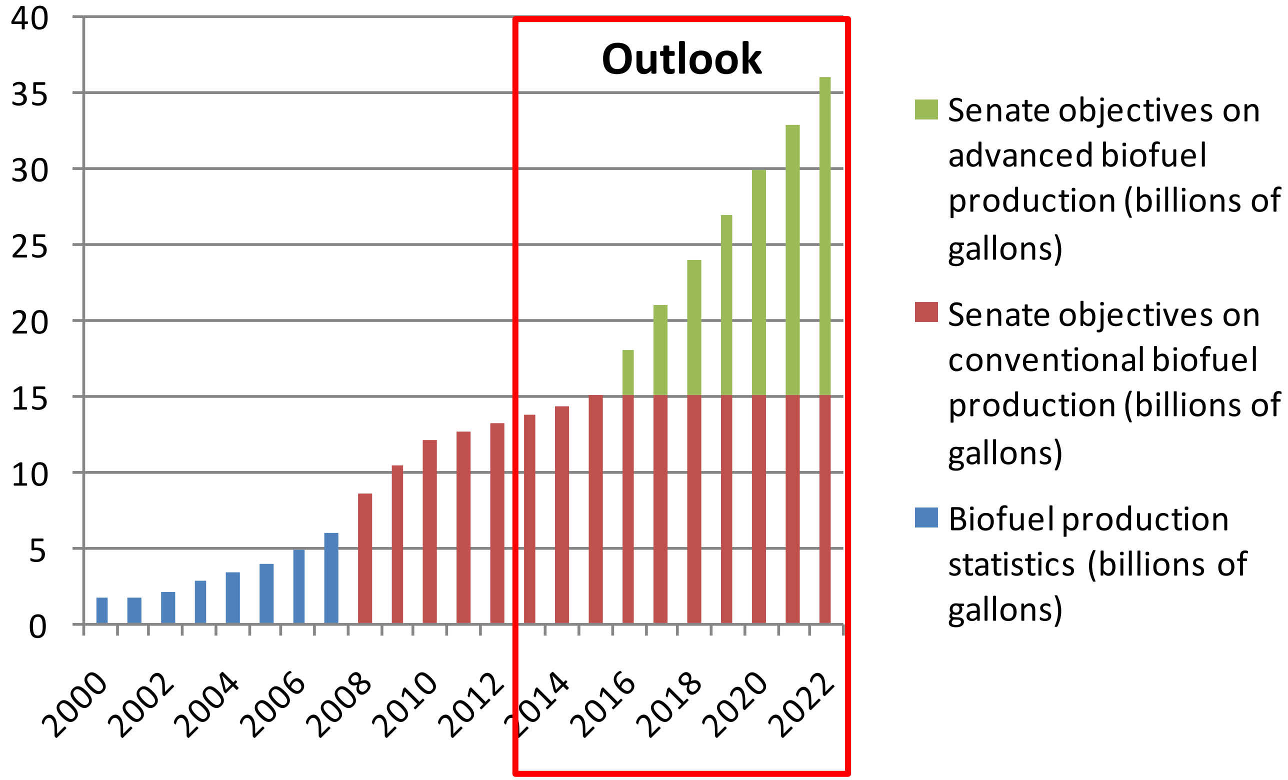
Ecuador

Adapted from Suh 2011

Bhutan

BIOFUEL PRODUCTION

- United States energy objectives



Adapted from Suh 2011

Future consumption and production

Impact — Demand side — Supply side

$$I = P * A * T$$

Technology

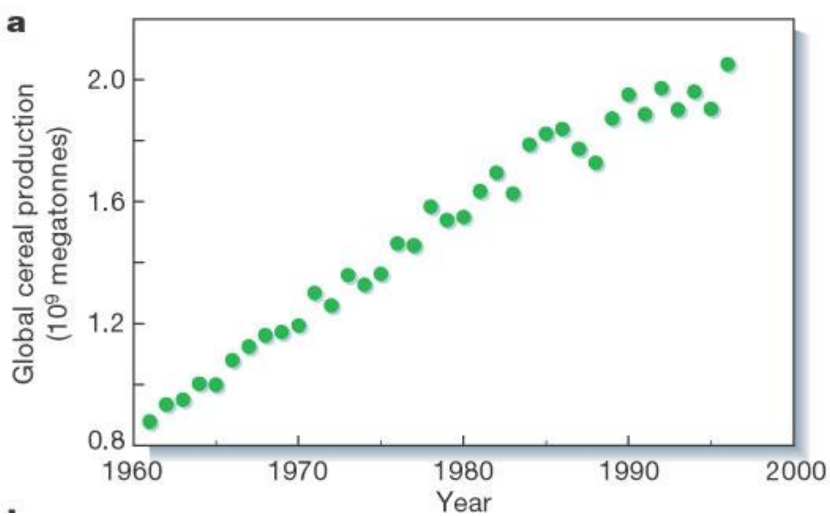
Adapted from Suh 2011

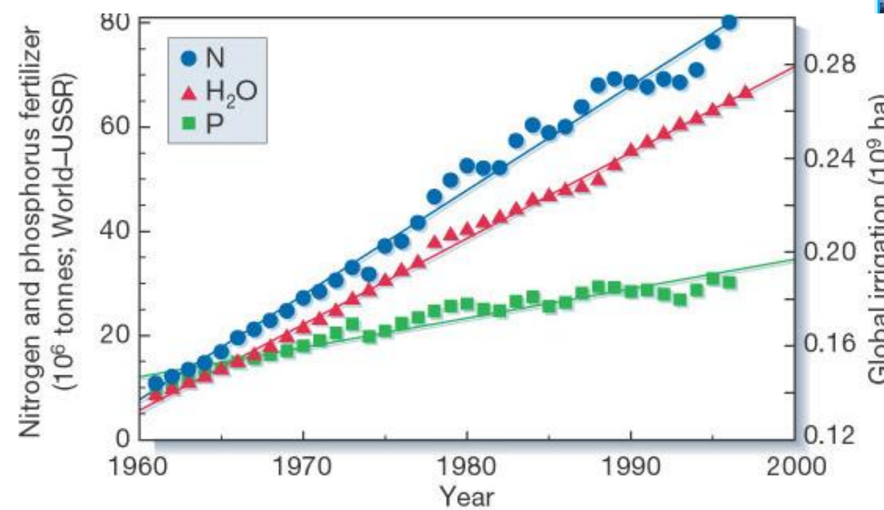
RELEVANT INDUSTRIAL SECTORS

- 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



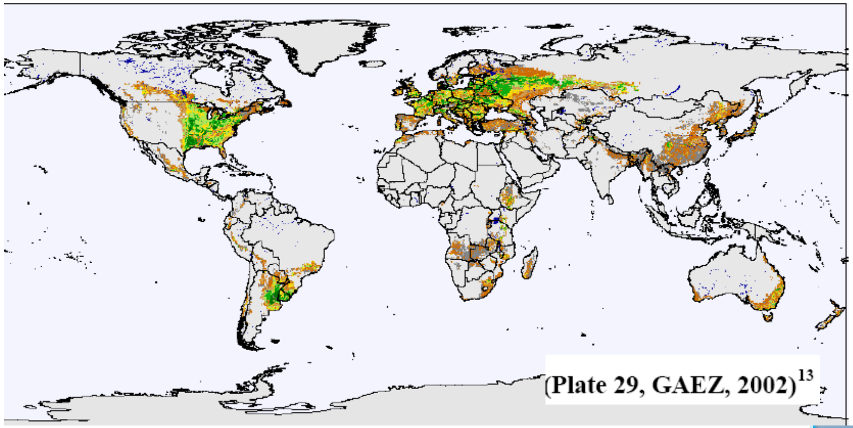


Tilman, D., et al. (2002): Agricultural sustainability and intensive production practices, *Nature*, 418. 671-677

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

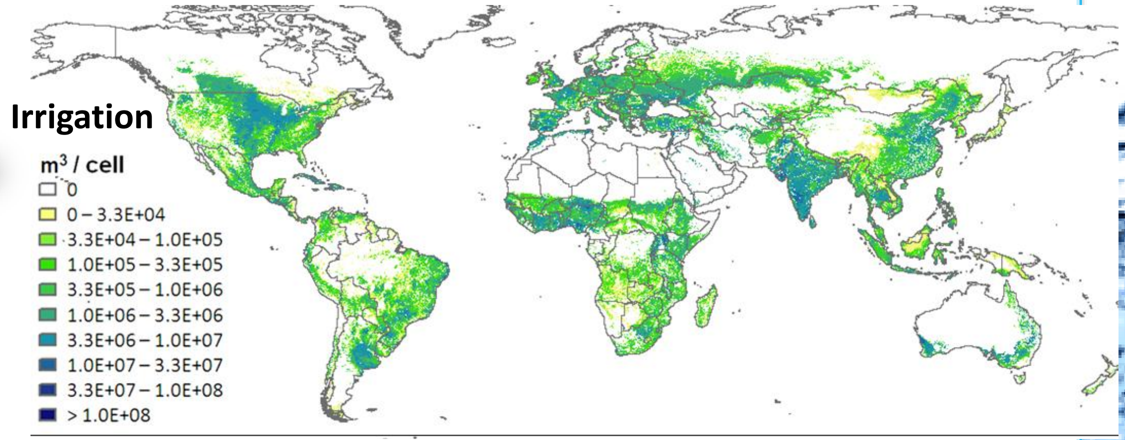


(Plate 29, GAEZ, 2002)[13]

ADDITIONAL IRRIGATION WATER CONSUMPTION IN 2050

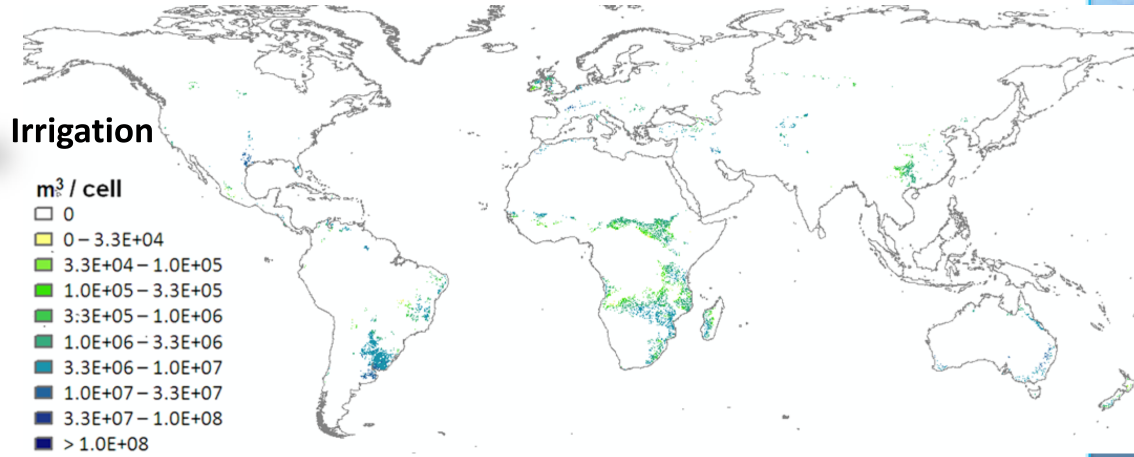
Strategies:

– Intensification & food waste reduction



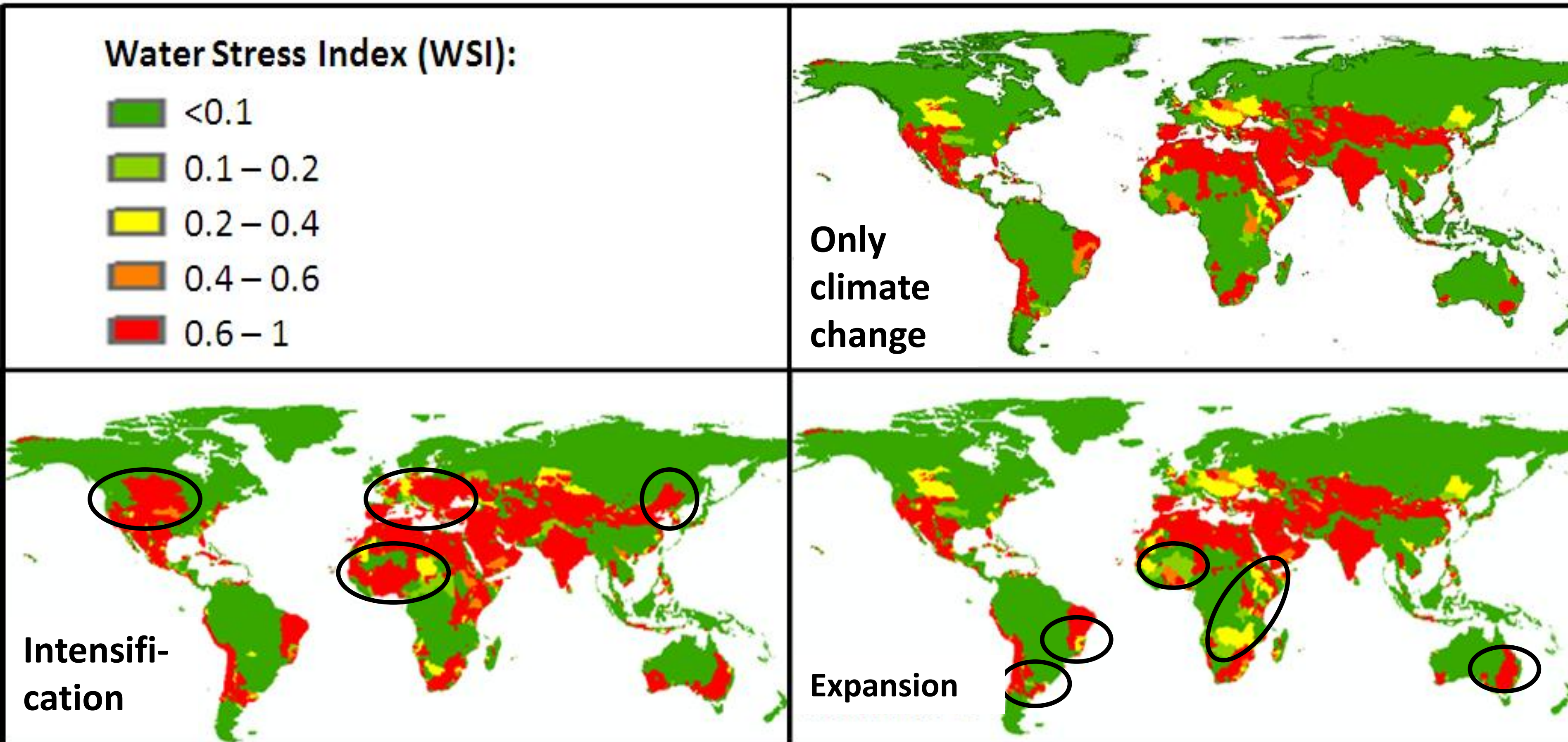
Irrigation:
+ 1125 km^3/yr
(64%)

– Expansion on pastures



Irrigation :
+169 km^3/yr
(10%)

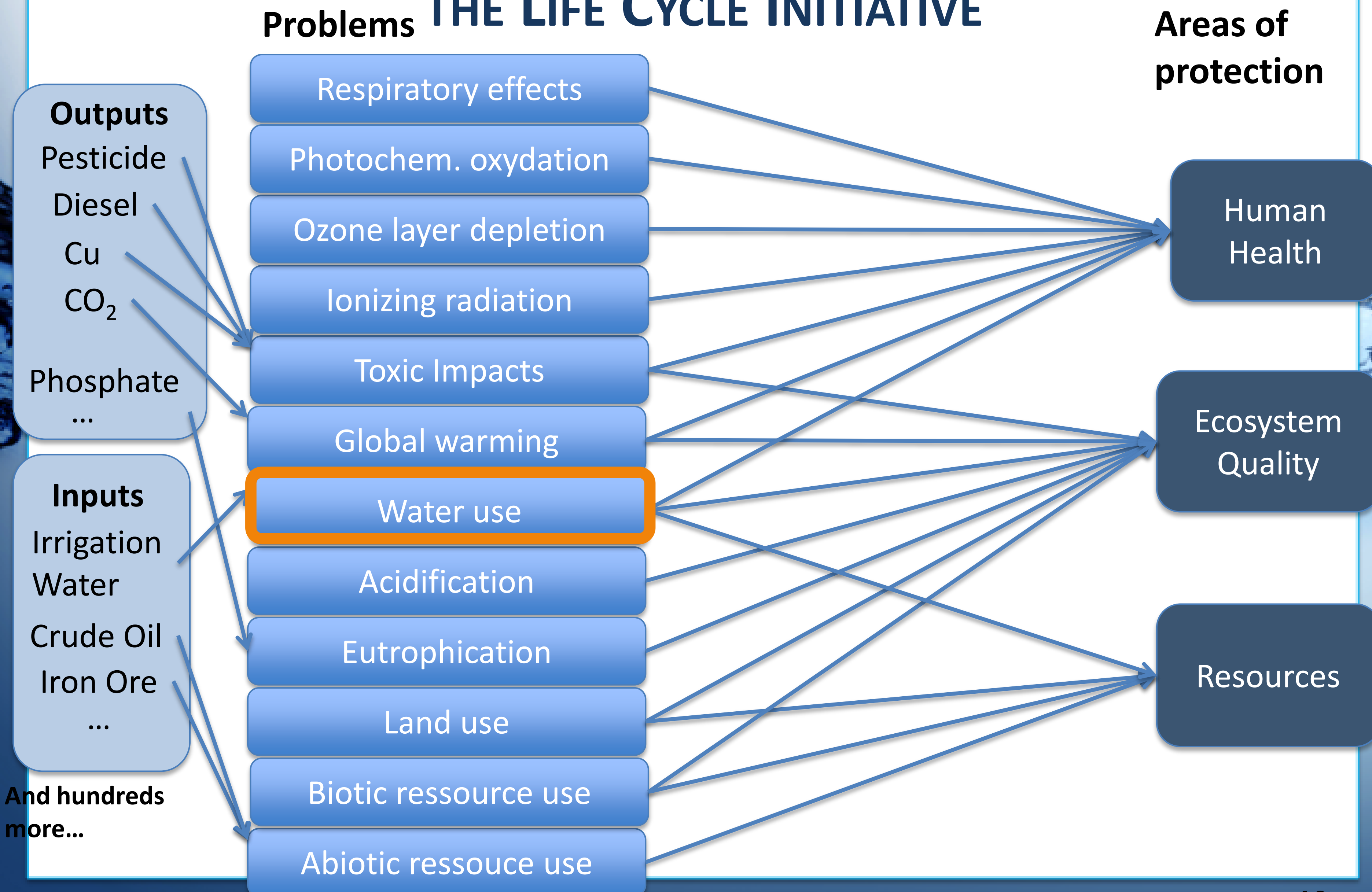
WATER STRESS INDEX IN 2050

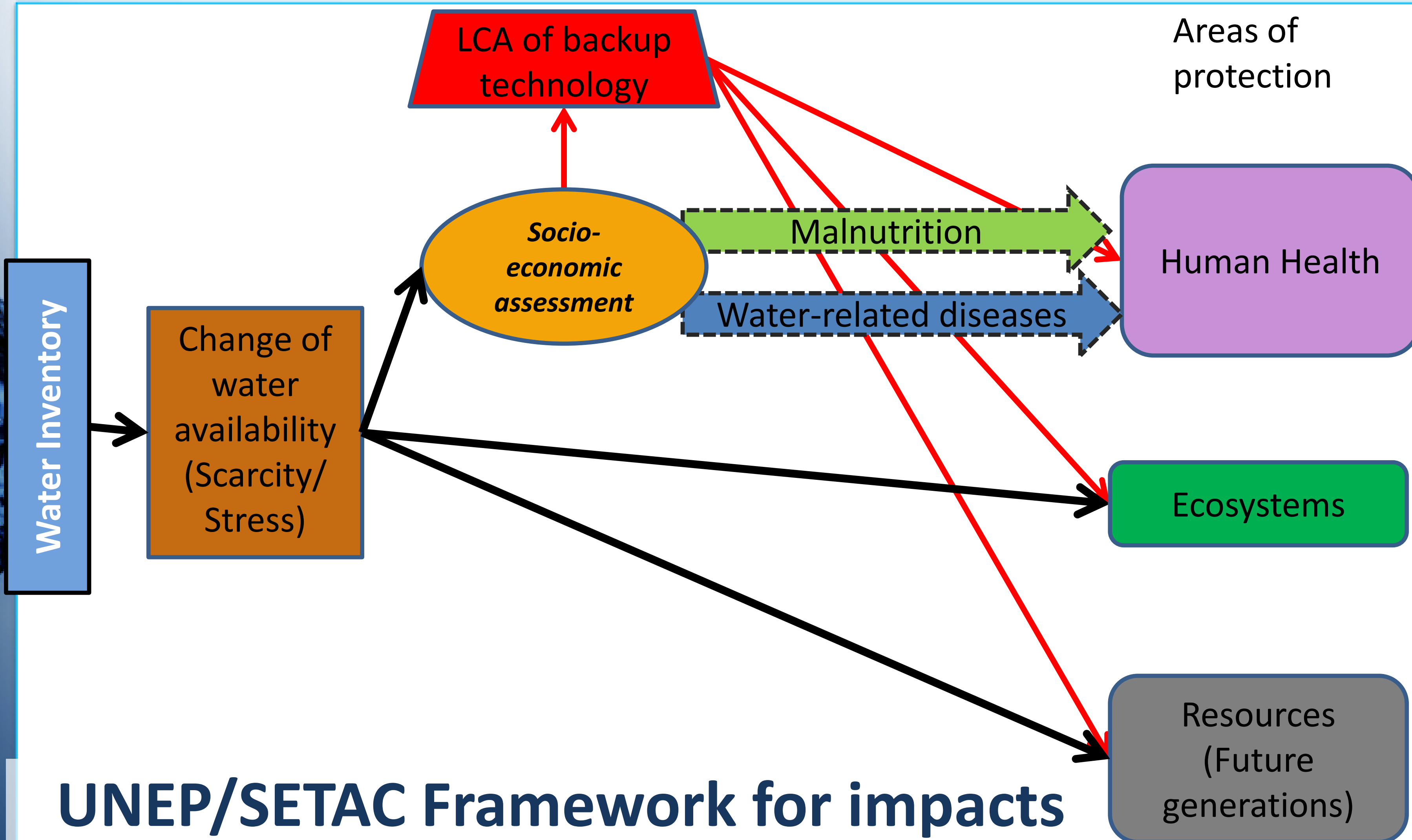


WATER AND LCA

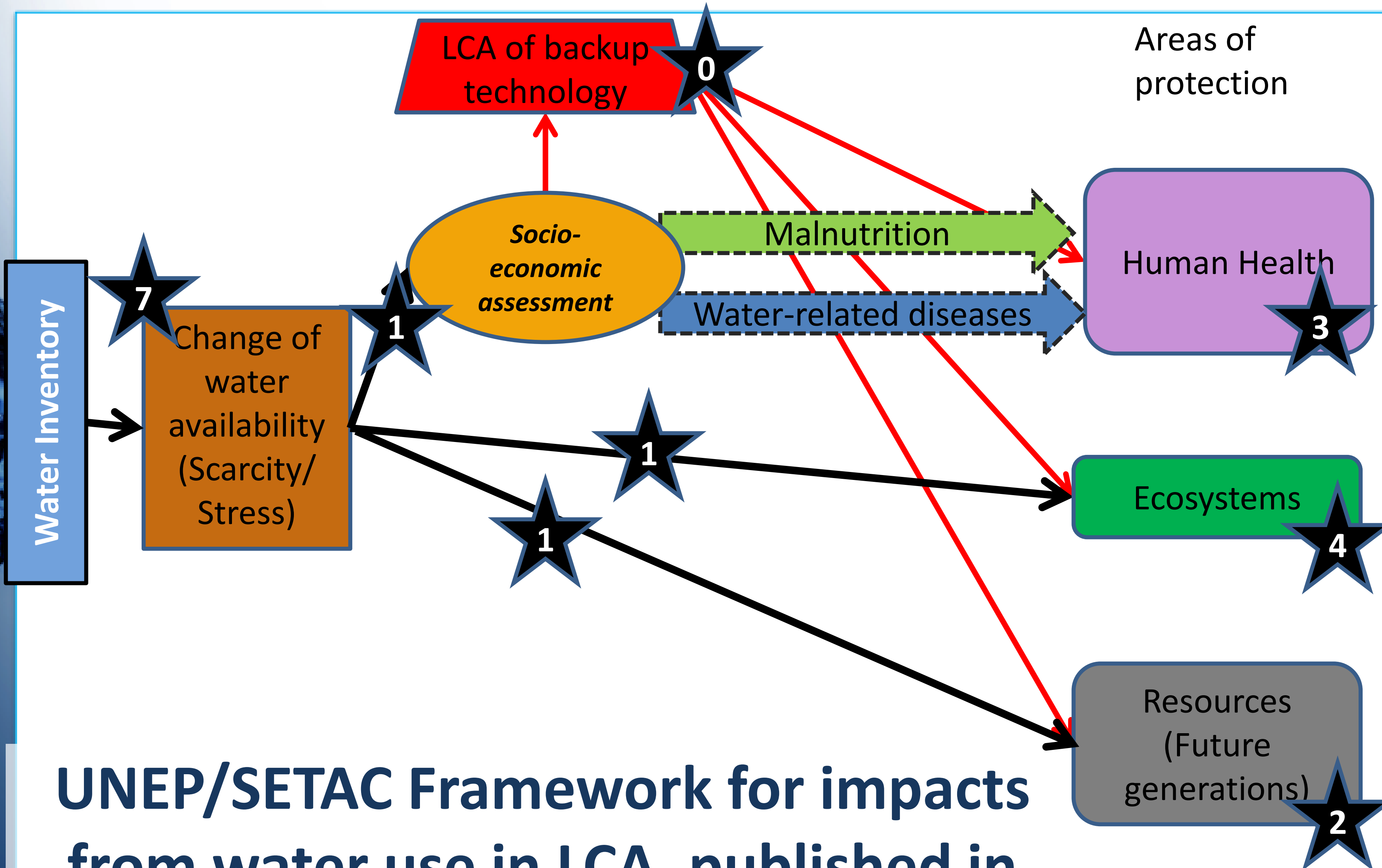
WULCA Working Group and Framework

Traditional framework of LCA impact pathways of the Life Cycle Initiative

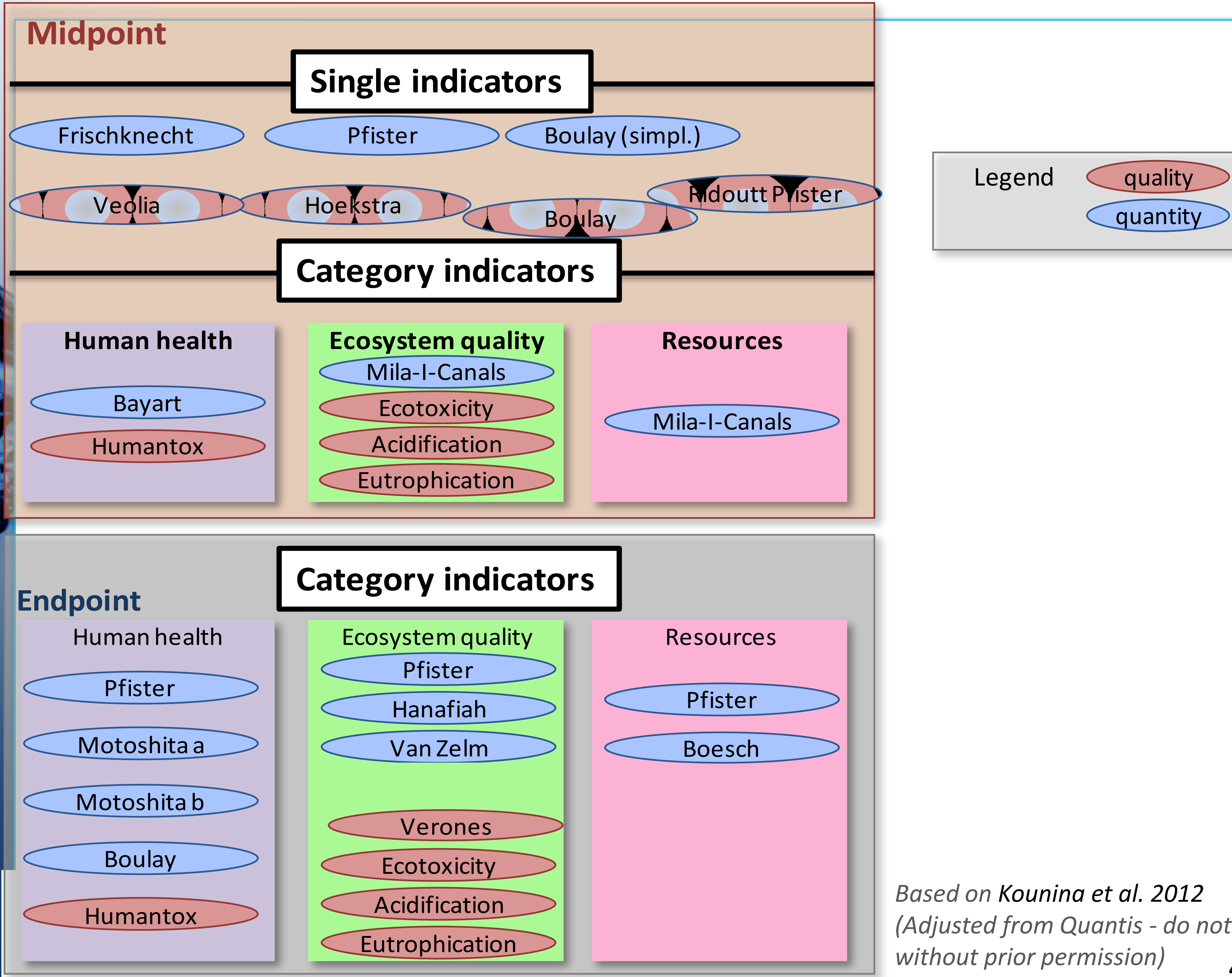




UNEP/SETAC Framework for impacts from water use in LCA, published in Bayart et al. 2010

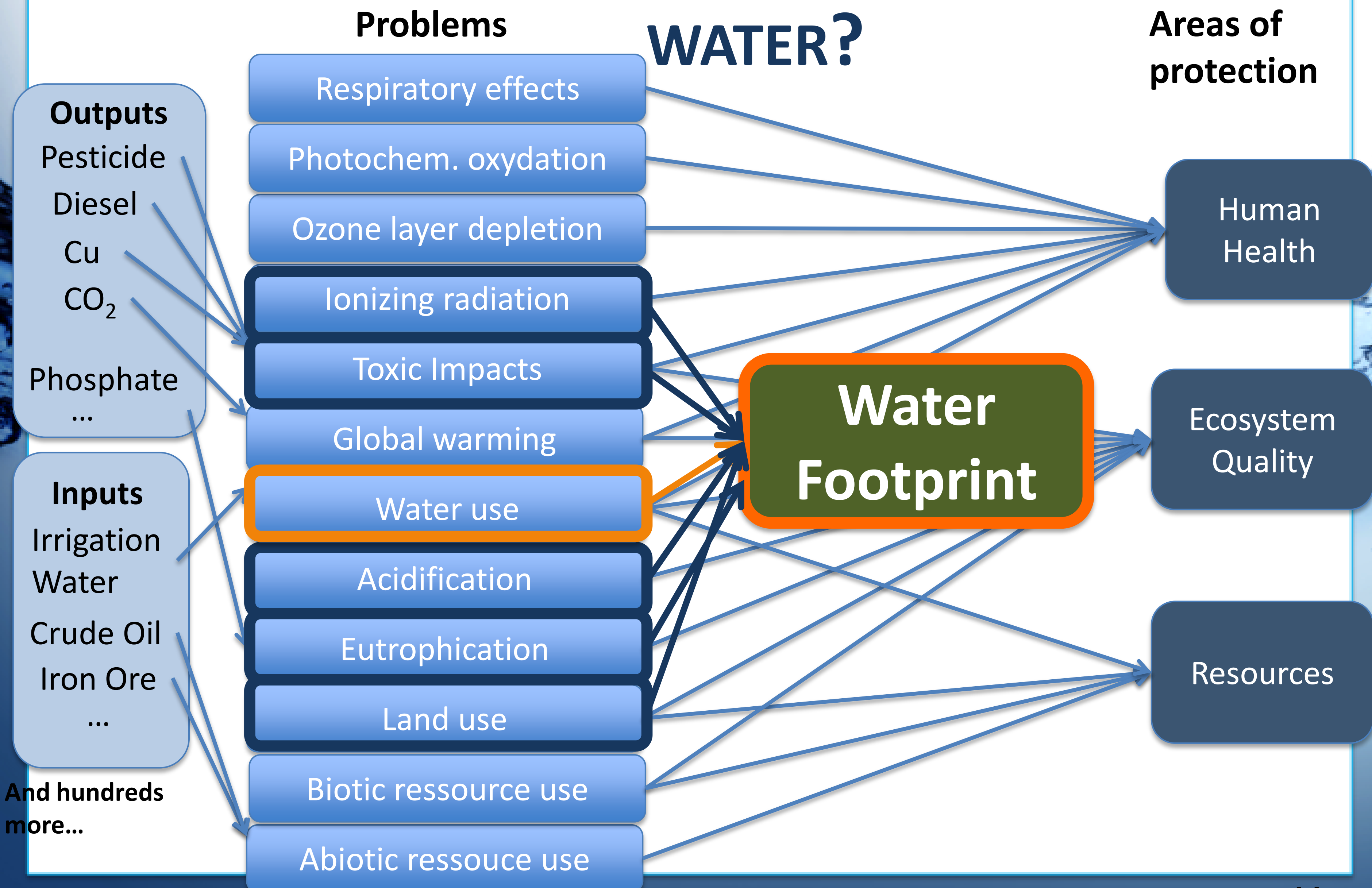


UNEP/SETAC Framework for impacts from water use in LCA, published in Bayart et al. 2010

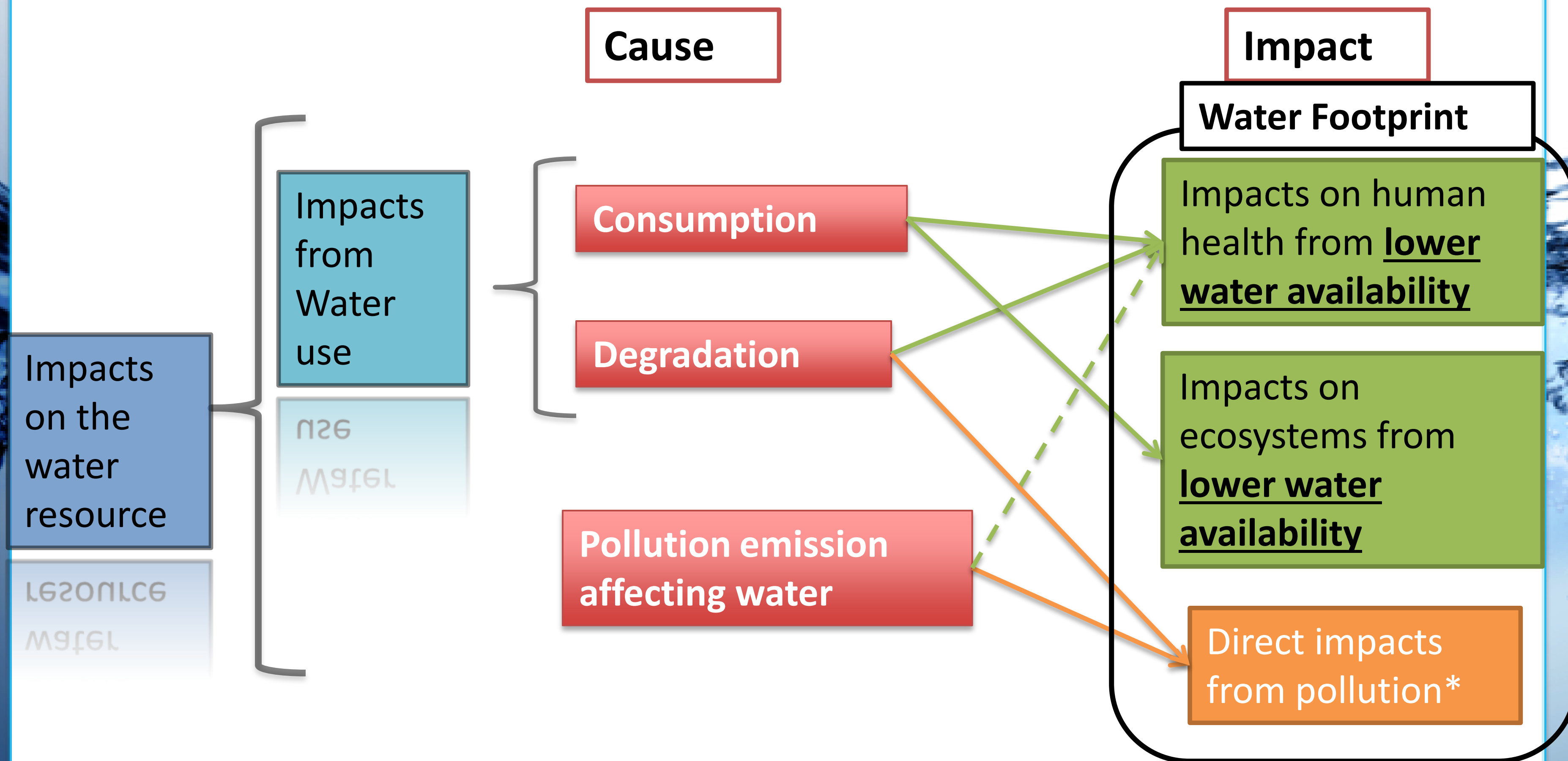


Based on Kounina et al. 2012
(Adjusted from Quantis - do not re-use without prior permission)

What are the impacts associated with water?

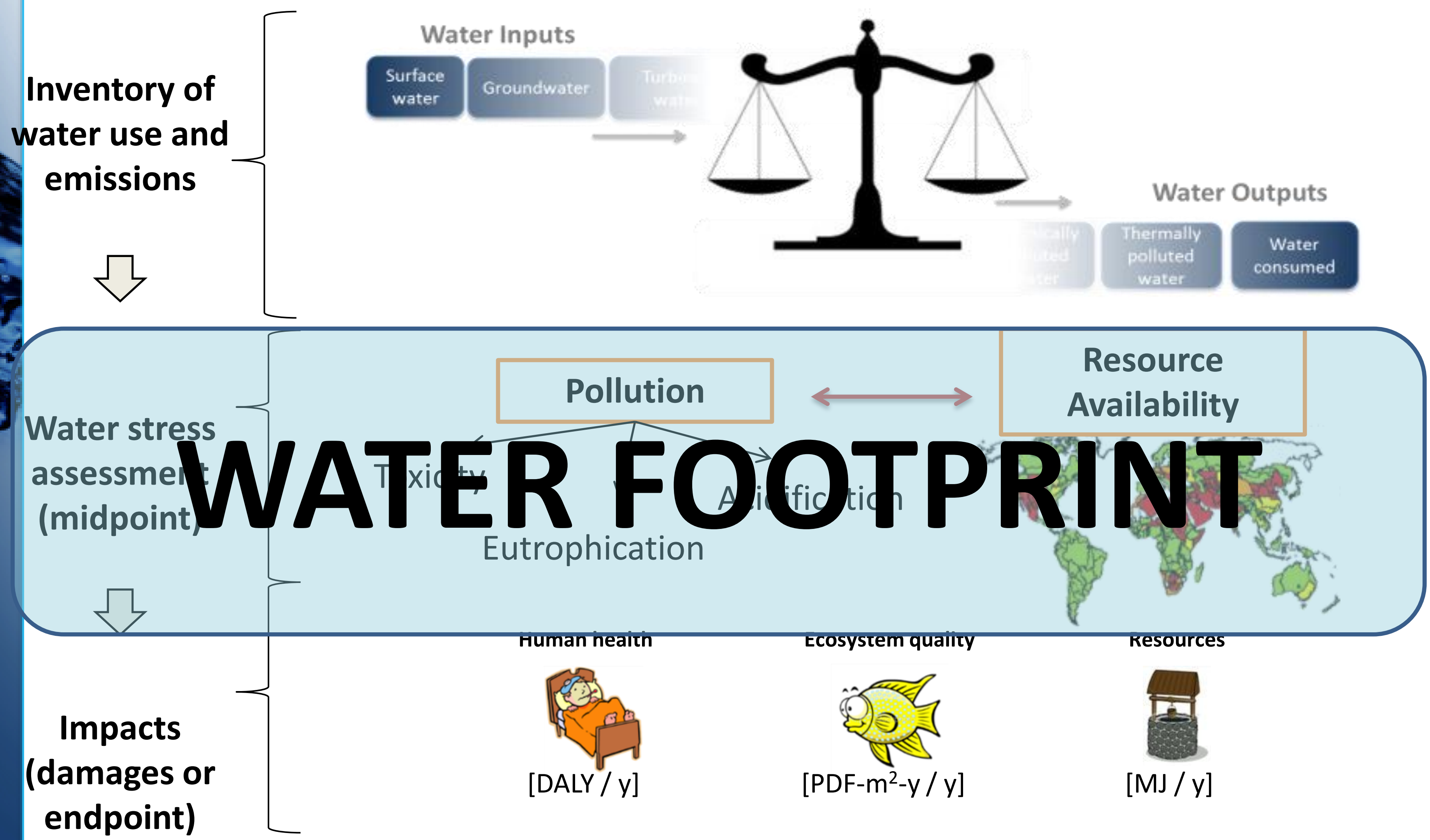


DISTINCTION IN WATER IMPACT MODELING

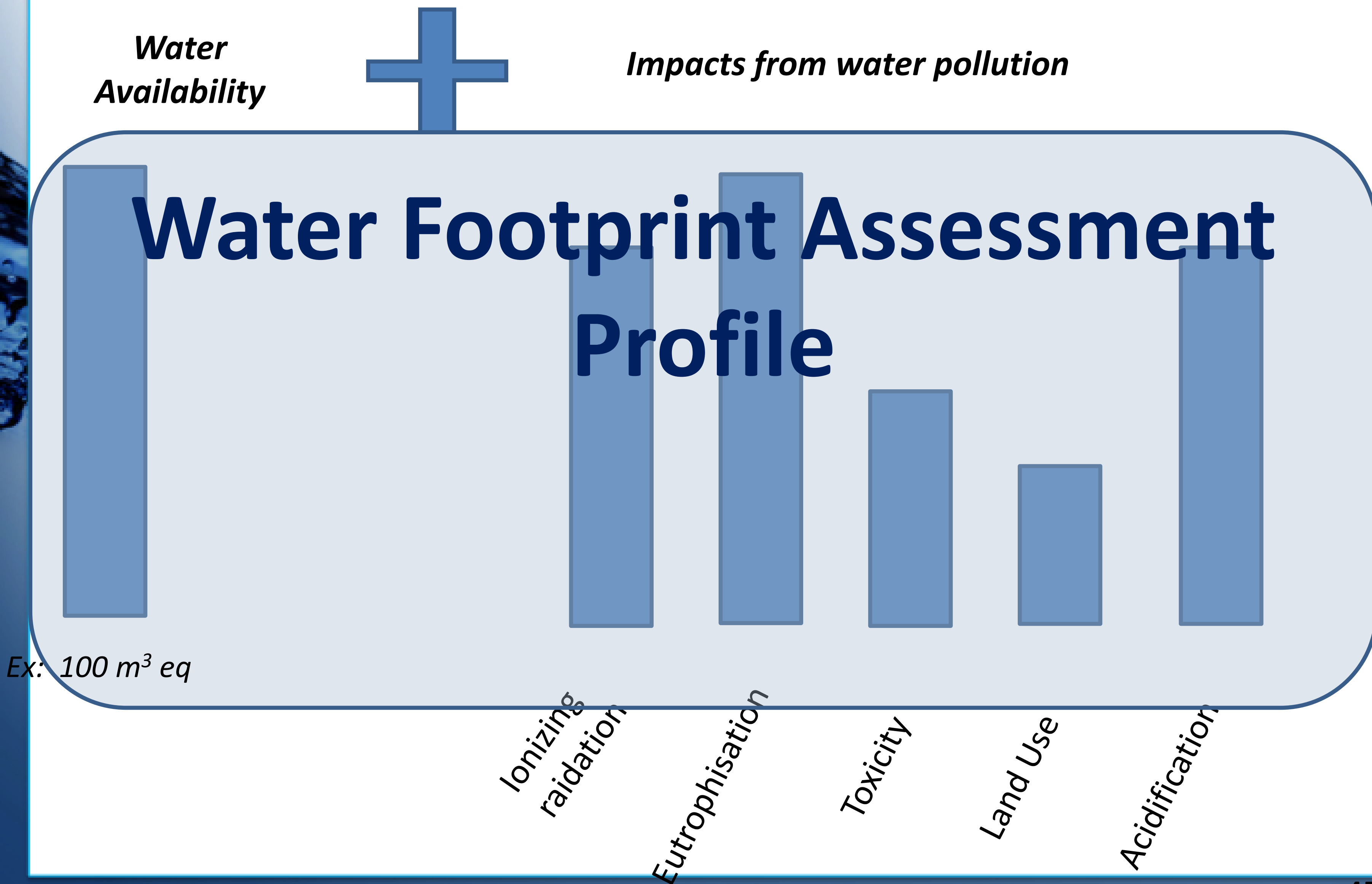


* From traditional LCA models including eutrophication, ecotoxicity, thermal, etc.

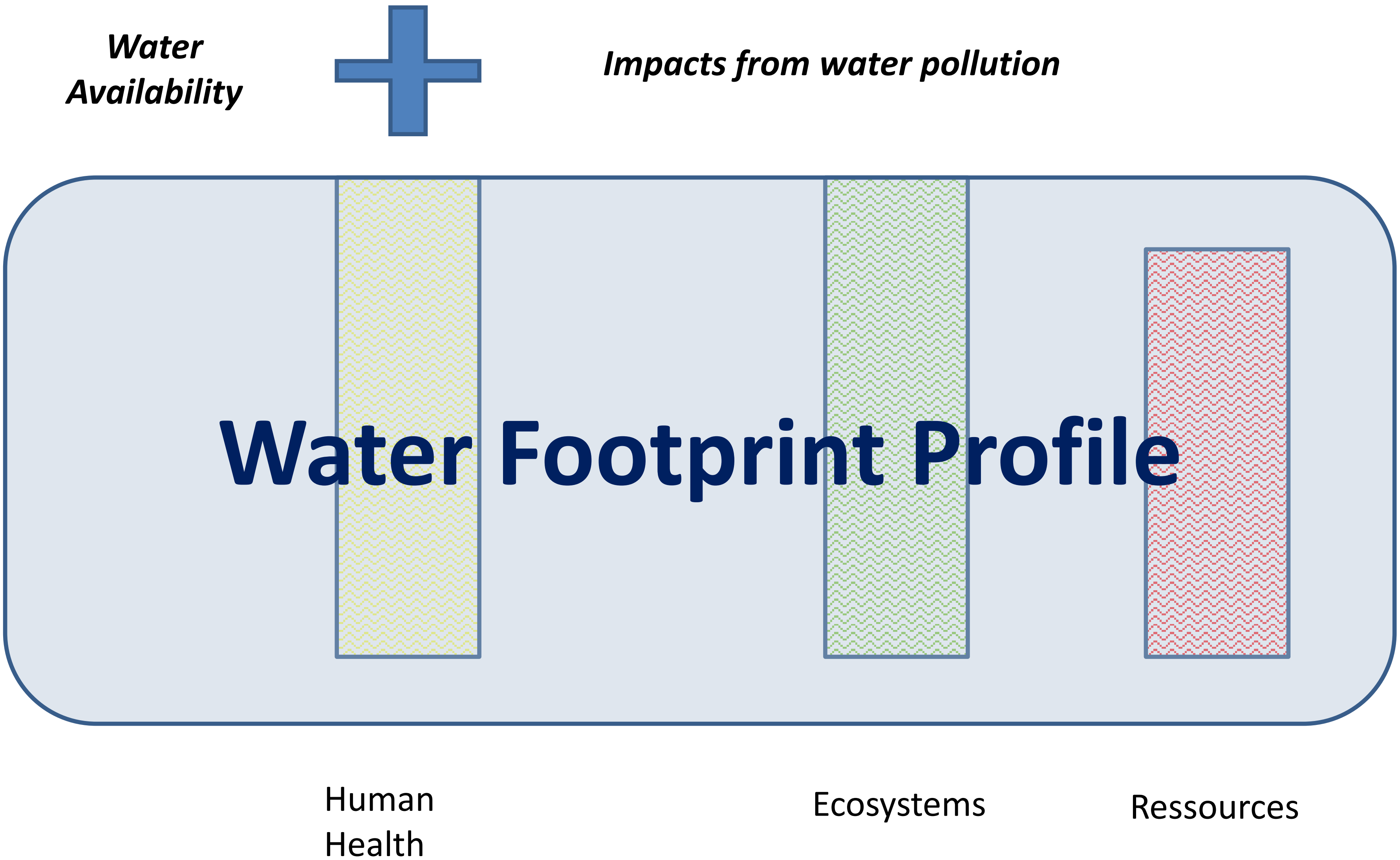
FROM INVENTORY, TO RISK, TO IMPACTS…



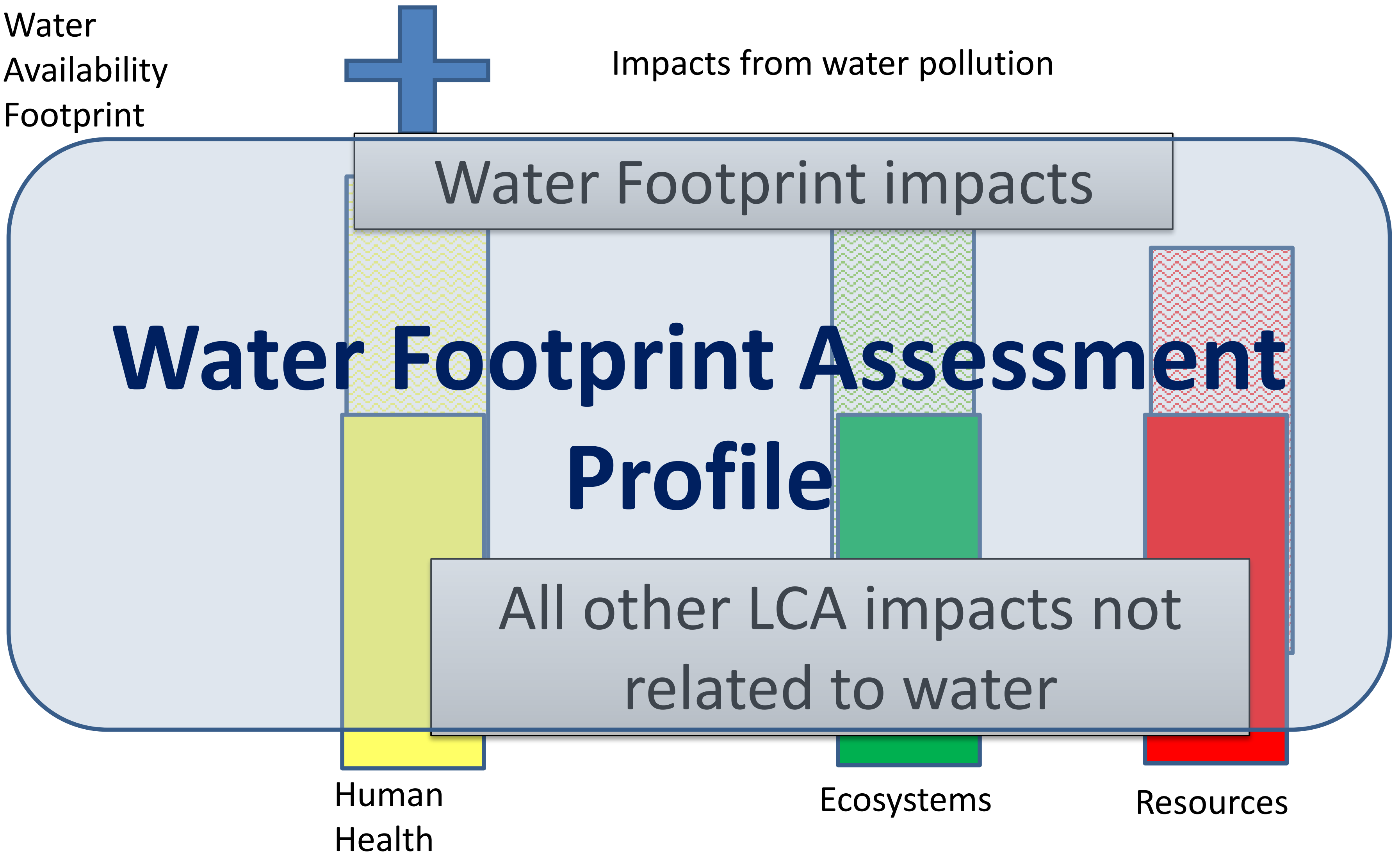
WATER FOOTPRINT PROFILE



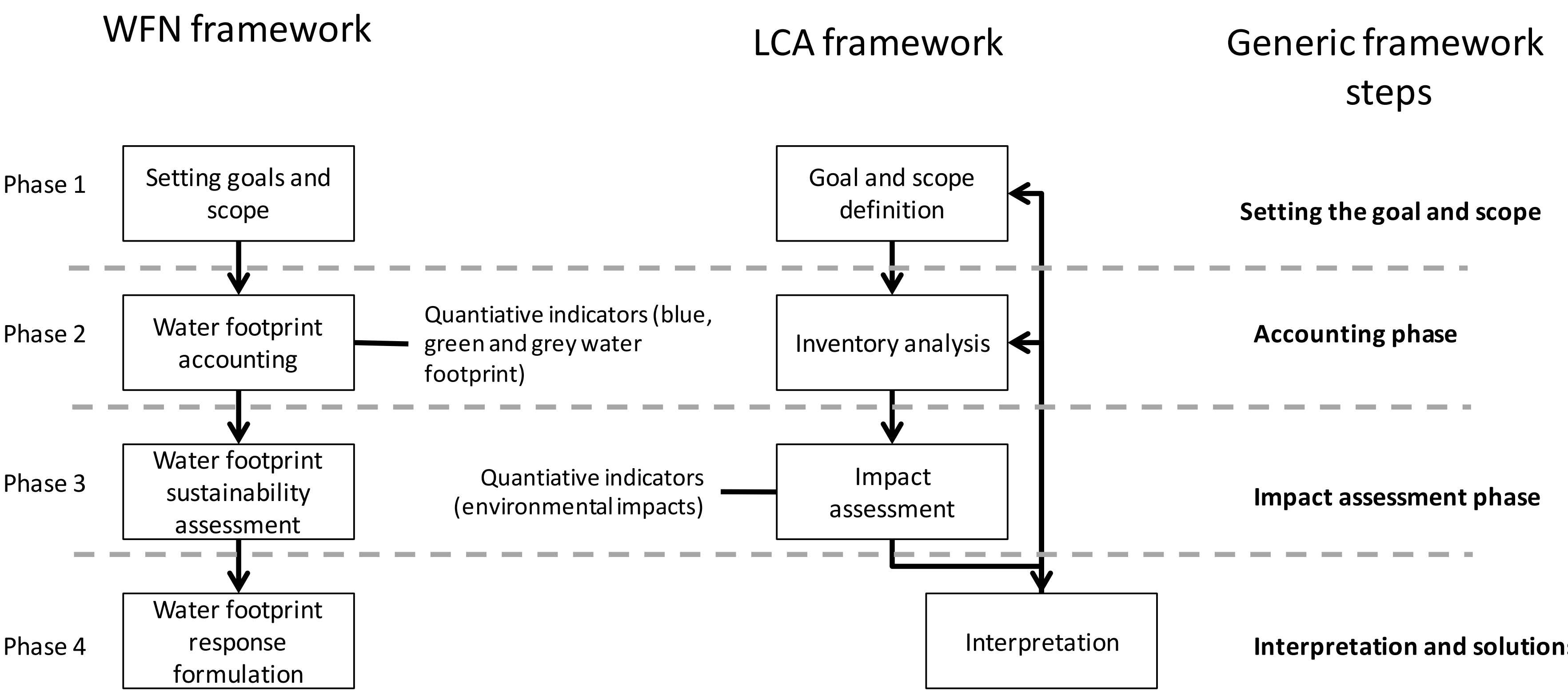
Water Footprint Profile



Water Footprint as part of LCA



Water Footprint Network vs LCA



Source: Boulay, Vionnet et Hoekstra, 2013

ISO STANDARDISATION PROCESS

ISO 14046, Water footprint – Requirements and guidelines

DIS ISO 14046 WATER FOOTPRINT REQUIREMENTS AND GUIDELINES

International Organization for Standardization

WG 8 set up by ISO/TC 207 subcommittee SC 5, *Life cycle assessment*.

Proposer & Secretariat:
SNV, Swiss Association for Standardization
Barbara Mullis, barbara.mullis@snv.ch
(formely 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

Participants:

15 – 30 Countries

35 – 80 experts

- Launch of the project:
  - 09.Mar.2009: NWIP Circulated in ISO/TC 207/SC 5
  - 09.Jun.2009: NWIP Submitted to vote
  - 26.Jun.2009: Cairo: NWIP Accepted as a Preliminary Working Item (PWI)
  - 25+.Sep.2009: List of P and O participants

Meeting every 6 months since 2009

WORKING MEETINGS

International Organization for Standardization

ISO 14046: In summary

International Organization for Standardization

- **“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

NWIP ACCEPTED IN CAIRO (JUNE 2009)

International Organization for Standardization

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

International Organization for Standardization

- 19-21.Nov.2009: First **working meeting**
  - (Stockholm, Sweden)
  - Title, Scope; Draft structure PWD
- 11-18.Jul.2010: Second **working meeting**
  - (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)
- 24-30.Jun.2012: Sixth **working meeting**
  - (Bangkok, Thailand)
  - Result for CD1 vote; Discussion on CD1
  - Decision to go for a CD2
- 9-12.Dec.2012: Seventh **working meeting**
  - (Padova, Italy)
  - Discussion on CD2
  - Decision to go for a DIS
- 23-26.Jun.2013: Eighth **working meeting**
  - (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

International Organization for Standardization

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

TECHNICAL REPORT

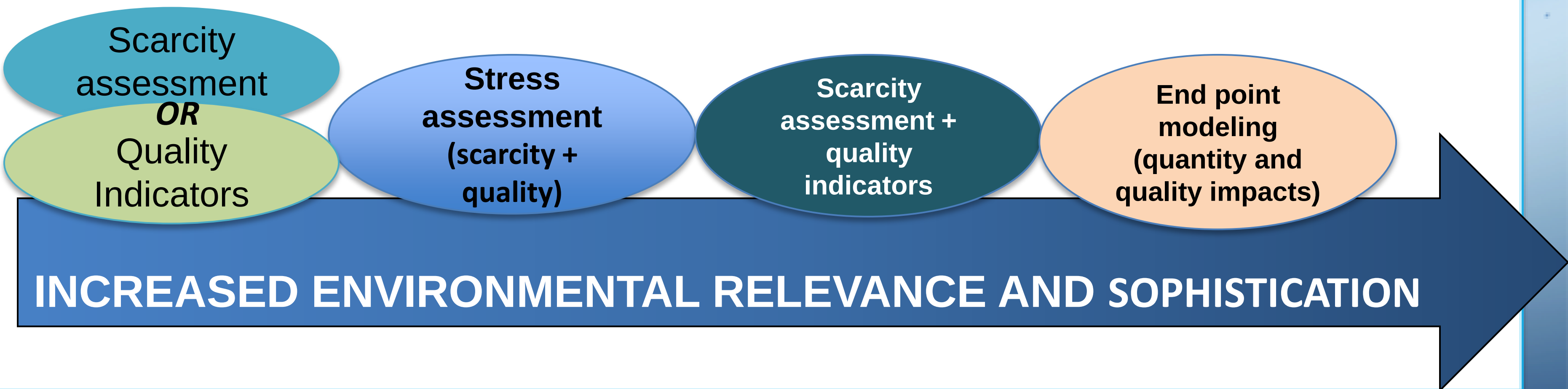
International Organization for Standardization

- 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

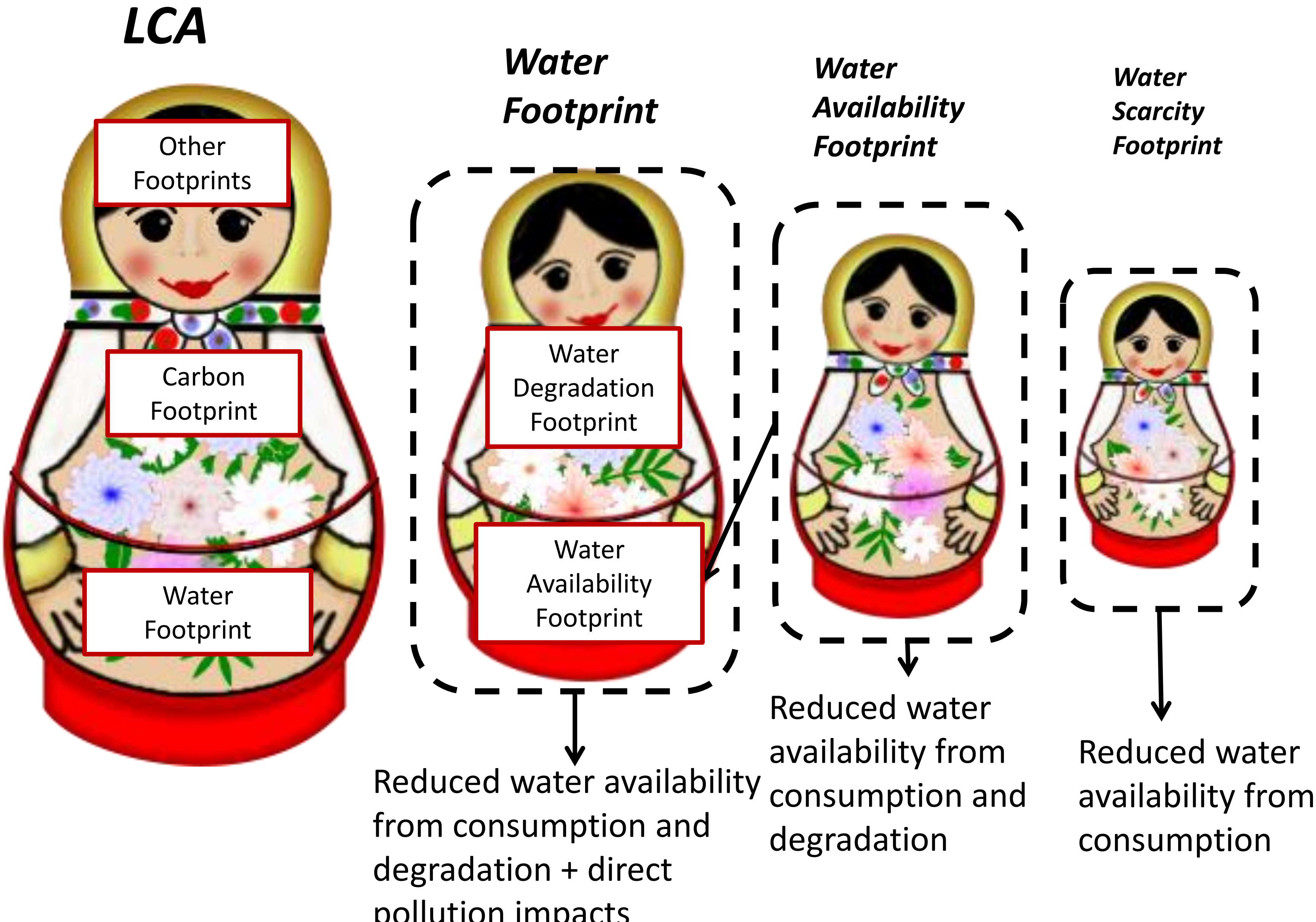
TYPES OF WATER FOOTPRINT METRICS AND ASSESSMENTS

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



WATER FOOTPRINT TYPES AS PER DIS ISO 14046

	Water availability	Water degradation
MIDPOINT		
Profile of midpoint indicators	-Water scarcity footprint OR - Water availability footprint	-Human toxicity -Ecotoxicity -Eutrophication -Acidification
ENDPOINT		
Human health	- Malnutrition and/or water related diseases	Human toxicity
Ecosystems	- Terrestrial ecosystems - Aquatic ecosystems	-Ecotoxicity -Eutrophication -Acidification

(blue line) "qualified" water footprint (ex: "degradation" WF, "scarcity" WF, etc)

(red line) Water footprint

INVENTORY

FRESHWATER REQUIREMENT FOR FOOD PRODUCTION

Food type	$m^3 \cdot kg^{-1}$	$m^3 \cdot 1{,}000 \cdot kcal^{-1}$
Cereals	1.5	0.47
Starchy roots	0.7	0.78
Sugarcrops	0.15	0.49
Pulses	1.9	0.55
Oilcrops	2	0.73
Vegetable oils	2	0.23
Vegetables	0.5	2.07
Average		0.53
Used in paper		0.5
Meat		4
Dairy products		>6

Rockstrom, et al, 2007: PNAS

[Hoekstra & Chapagain, 2008] Source WFN, 2012

[Hoekstra & Chapagain, 2008]

Source WFN, 2012

[Hoekstra & Chapagain, 2008] Source WFN, 2012

[Hoekstra & Chapagain, 2008]

Source WFN, 2012

[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

WATER FOOTPRINT INVENTORY
REGIONALIZATION MATTERS

Example 1: Cup of coffee

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

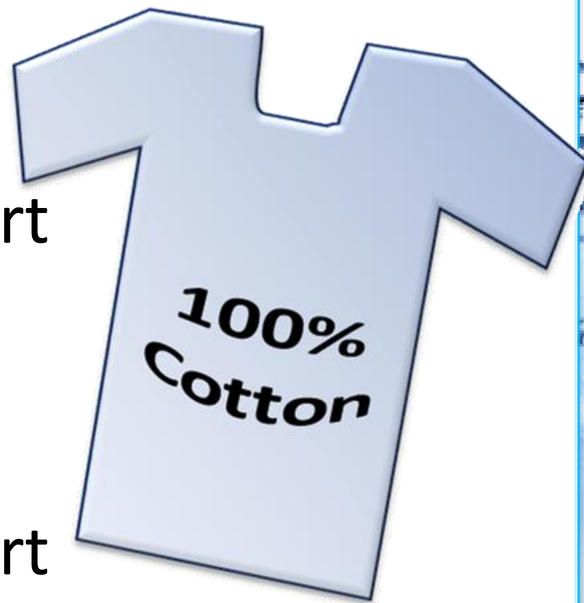
- Regionalised calculations
  - Virtual water : **157** litre/cup
  - Irrigation water: **46** litre/cup
  - **Scarcity weighted irrigation water: 6 litre/cup**

➡ **Footprint = 4% of virtual water**

Water Footprint Inventory Regionalization matters

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

[Hoekstra & Chapagain, 2008]

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)

99%

Water

► 24000 litres for drinking

► 7000 litres for servicing.

1%

[Hoekstra & Chapagain, 2008]

[Hoekstra & Chapagain, 2008]

[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

WATER FOOTPRINT

≠

Tunisian beef steak

UK beef steak

WHAT ABOUT WATER QUALITY???

Meat versus vegetarian diet

	Meat diet		Vegetarian diet	
	kcal/day	litre/day	kcal/day	litre/day
Industrial countries	3400	3600	3400	2300
Developing countries	2700	2050	2700	1750

Source WFN, 2012

VEGETARIANS ALL OVER THE PLACE?

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

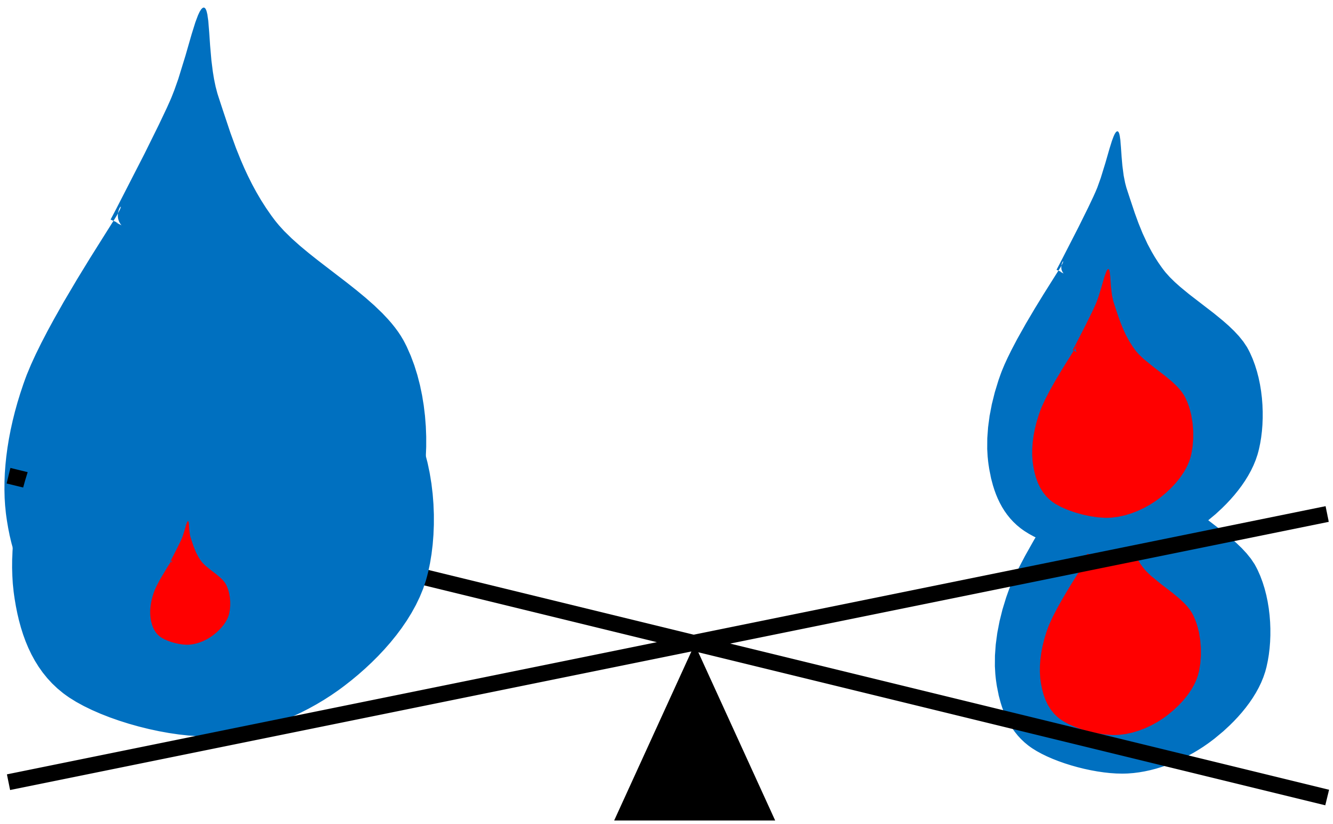
Photo by substack under the Creative Commons Attribution License 2.0: http://m.flickr.com/#/photos/substack/3131586597/

Relevance of production system

Source WFN, 2012

WATER FOOTPRINT INVENTORY

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

Water Footprint Inventory

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

INVENTORY

Type and quantity of water resources used;

Precipitations, Surface water, Ground water, Fossil water, Brackish water, Sea water.

Water Quality parameters (Physical, chemical, bacteriological, qualitative)

PH, TDS, SS, TN, E-coli count, Temperature, Color, Turbidity, Fe,………..

Forms of consumptive water use;

Evaporation, transpiration, integration in product, discharge to sea, discharge into another water basin.

Forms of non consumptive water use,

Discharge to another water resource type within the same drainage basin, In stream use

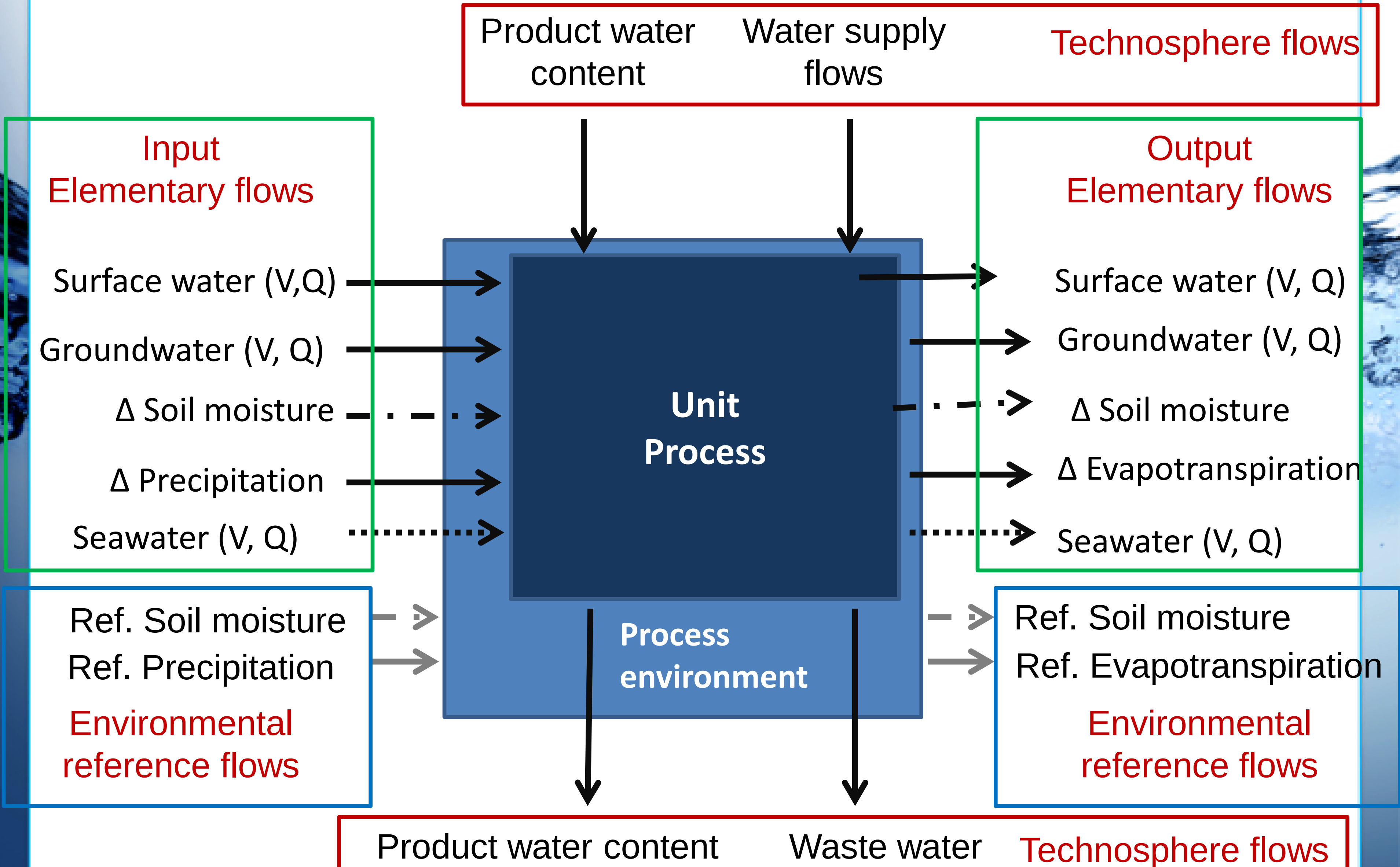
Emissions to air water and soil where these are relevant;

SO_2, Vn, Radioactivity, N,P, K, Bacteriology

Water scarcity indices and any other data that may be relevant…………………………

Water Footprint Inventory

Unit process water inventory

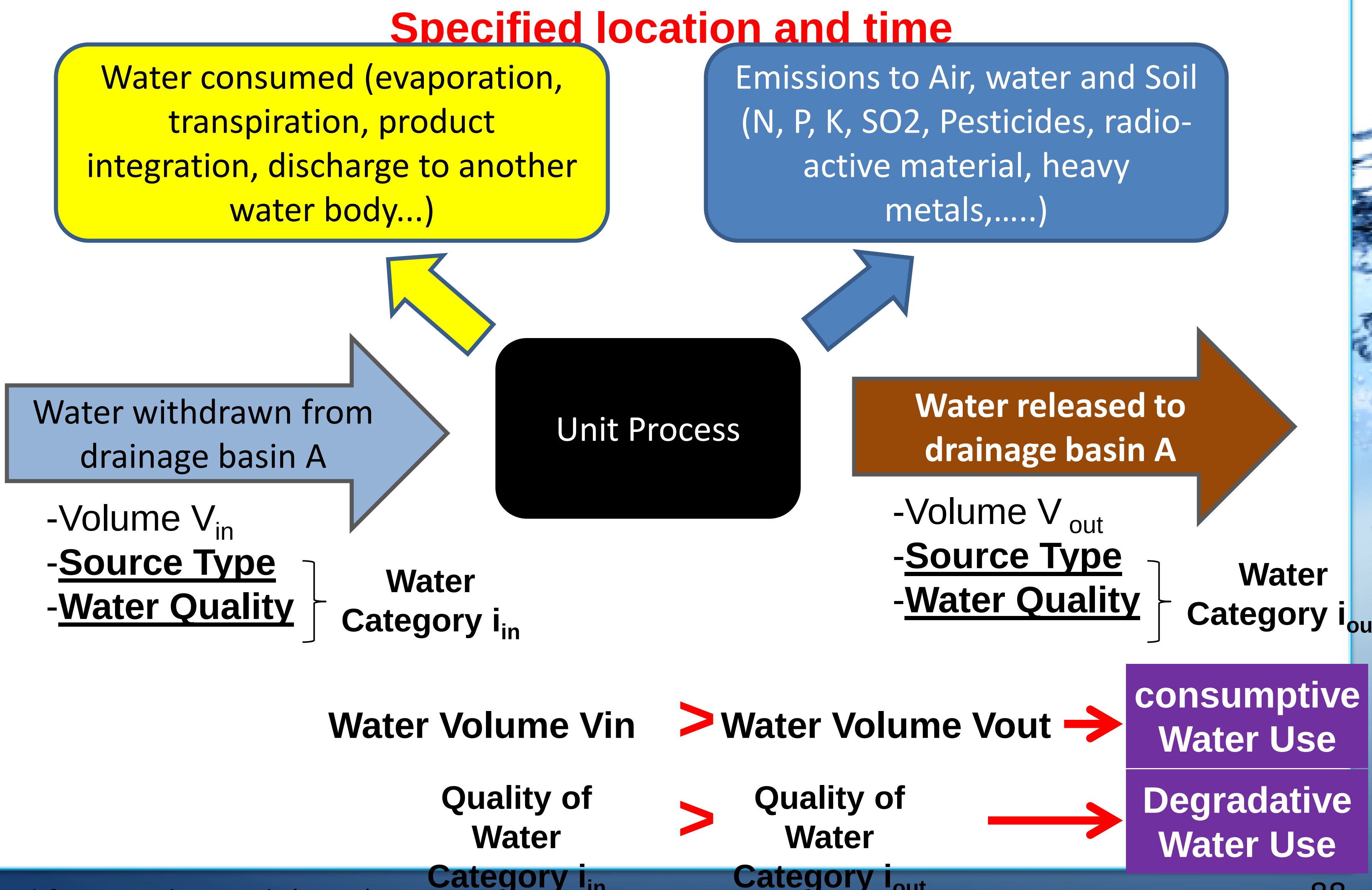


Adapted from Pfister et al.

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



Adapted from Boulay et al, (2011)

Water Footprint Inventory

Water quality (functionality)

Water Categories and Dij		Excellent	Good	Average	Average - Tox
		i = 1	i = 2a	i = 2b	i = 2c
Contamination		low coliforms, low toxic	low coliform, medium toxic	Medium coliform, medium toxic	Low coliform, higher toxic
PARAMETERS	Units				
General parameters					
Fecal coliforms	UFC/100ml	20	200	2000	200
Microcystin-LR	mg/l	0.001	0.001	0.001	
True color	Color unit (CU)	15	50	50	100
Suspended Solids	mg/l	25	25	100	25
Total Dissolved Solids)	mg/l	500	500	500	2000
Biochemical Oxygen Demand	mgO_2/l	5	5	5	5
Total Nitrogen	mg N/L	30	30	30	30

- **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.**

Boulay et al, 2011

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

Water Footprint Inventory

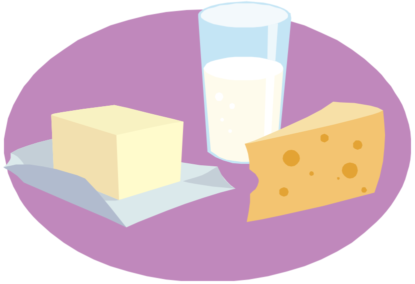
Pizza Margherita, the Swiss case

Main Ingredients

Tomato, vegetables (raw crops)

Wheat flour, olive oil (processed crops)

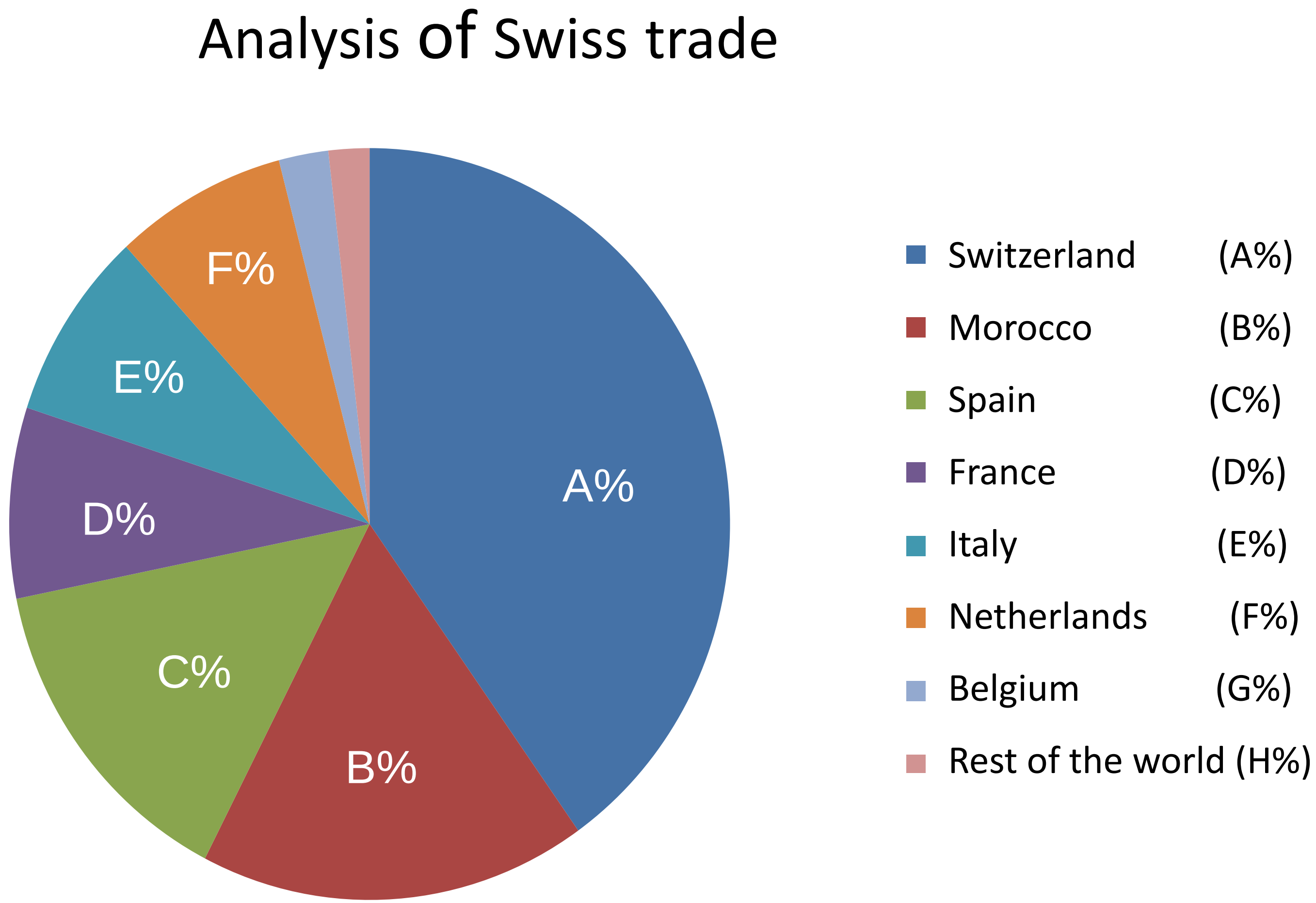
Mozarella, ham, mortadella (animal products)



Adapted from *Eymann (2010)*

Water Footprint Inventory

Origin of Tomatoes



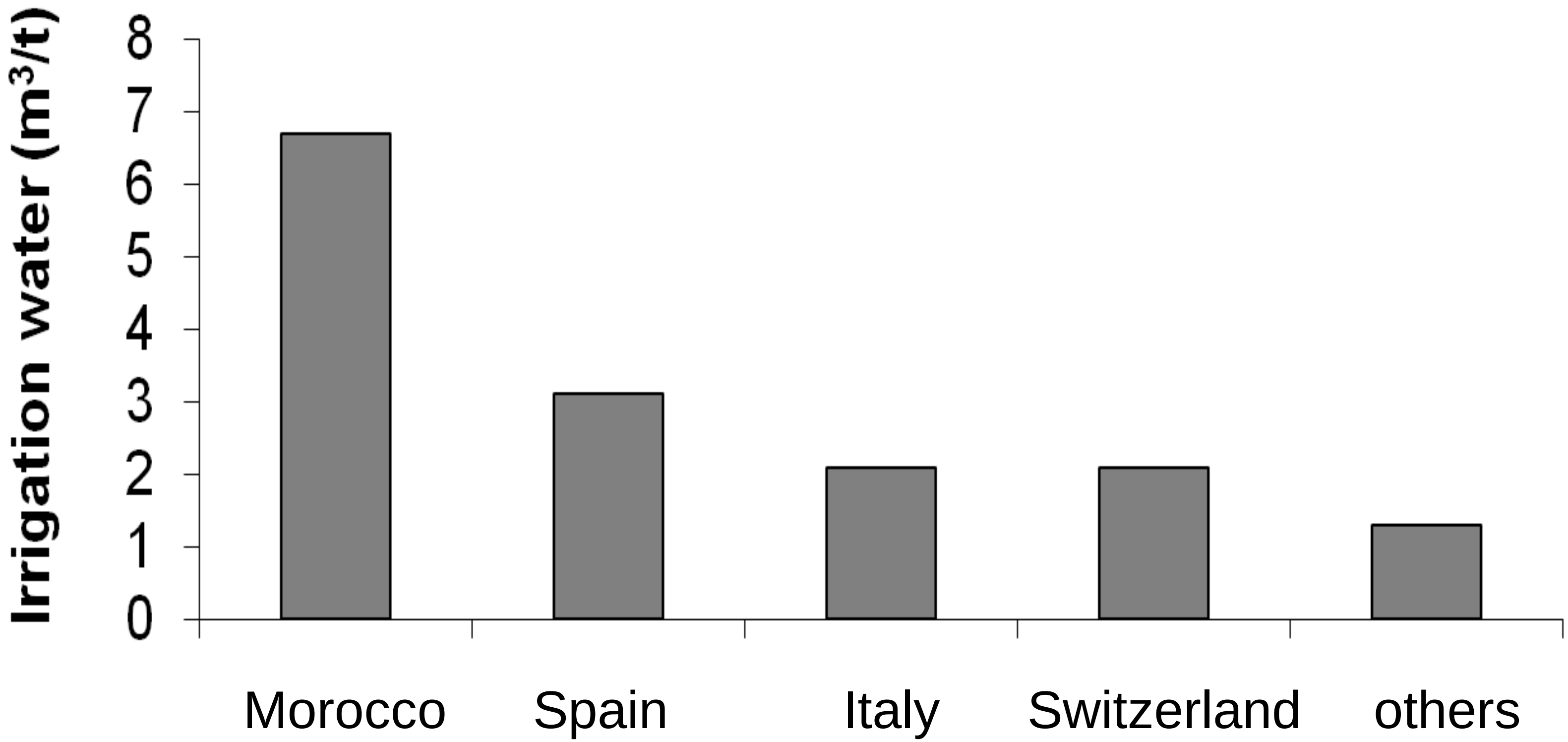
Adapted from *Eymann (2010)*

WATER FOOTPRINT INVENTORY

Irrigation water consumption of
tomato supply mix in Switzerland

Weighted average water consumption:

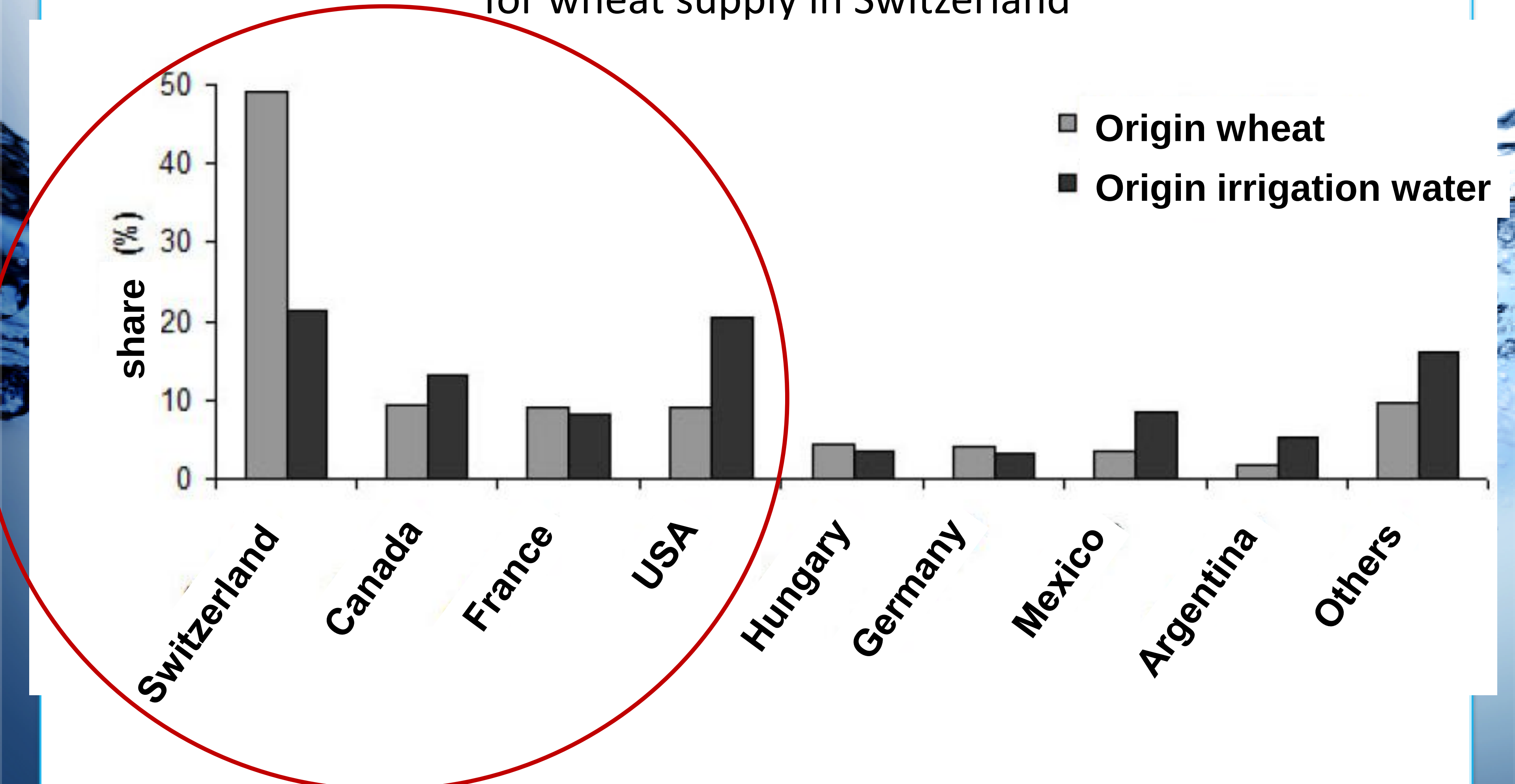
= 6.8*B% + 3.1*C% + 2.5*E% + 2.5*A% + 1.2*(D% + F% + G% + H%) m^3/t



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)

Flour

Husks

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

WATER FOOTPRINT INVENTORY

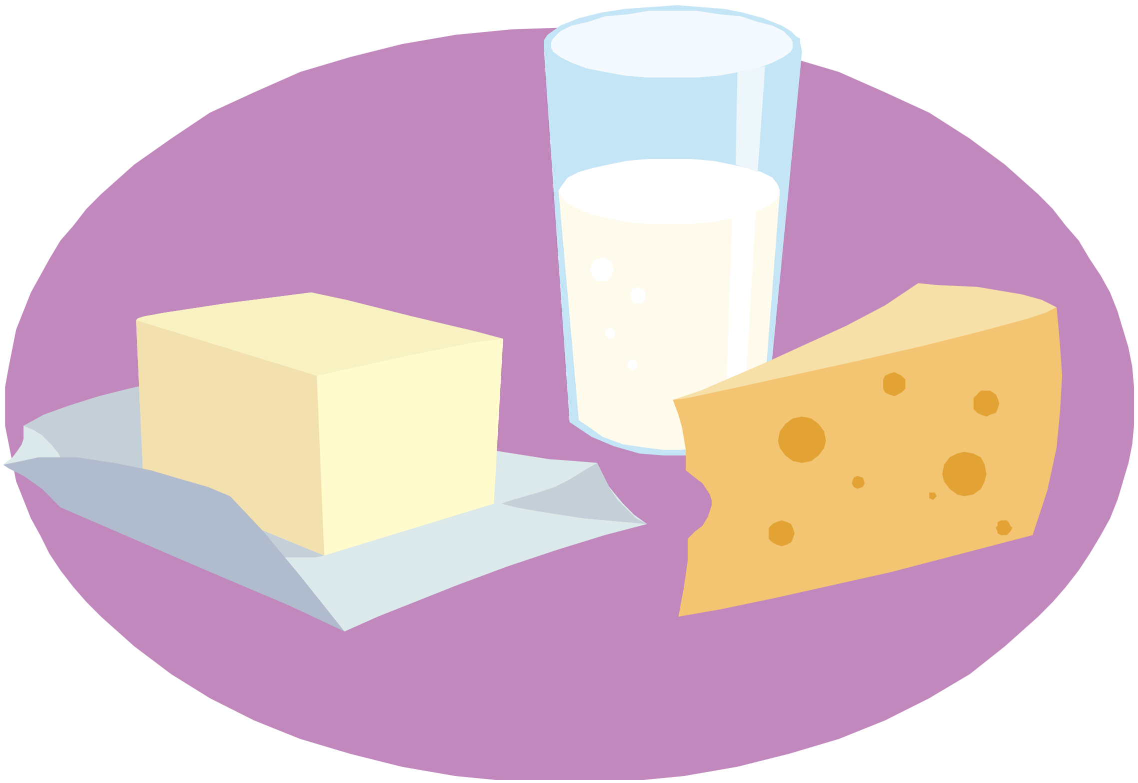
Irrigation water allocation to flour

Average Irrigation water consumption · **Value fraction flour** / **Product fraction flour** = **Allocated irrigation flour**

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

Water Footprint Inventory

Animal Products



Adapted from *Eymann (2010)*

Water Footprint Inventory

Grassilage:
20 t/Cow
16 m^3/t

Maize
22 t/Cow
79 m^3/t

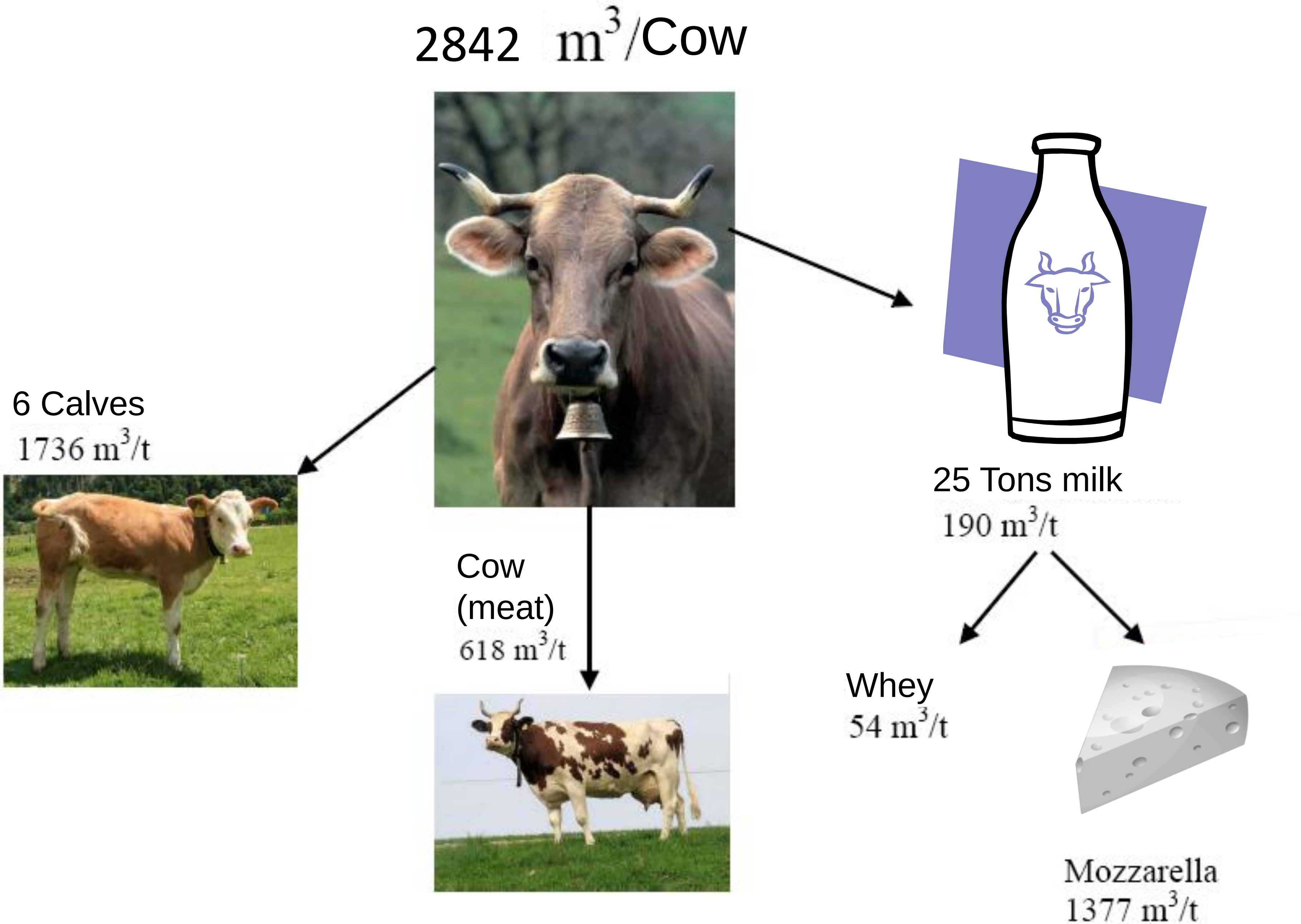
Hay
4.6 t/Cow
40 m^3/t

Others:
8.4 t/cow
54 m^3/ton

Drinking water
146 m^3/Cow

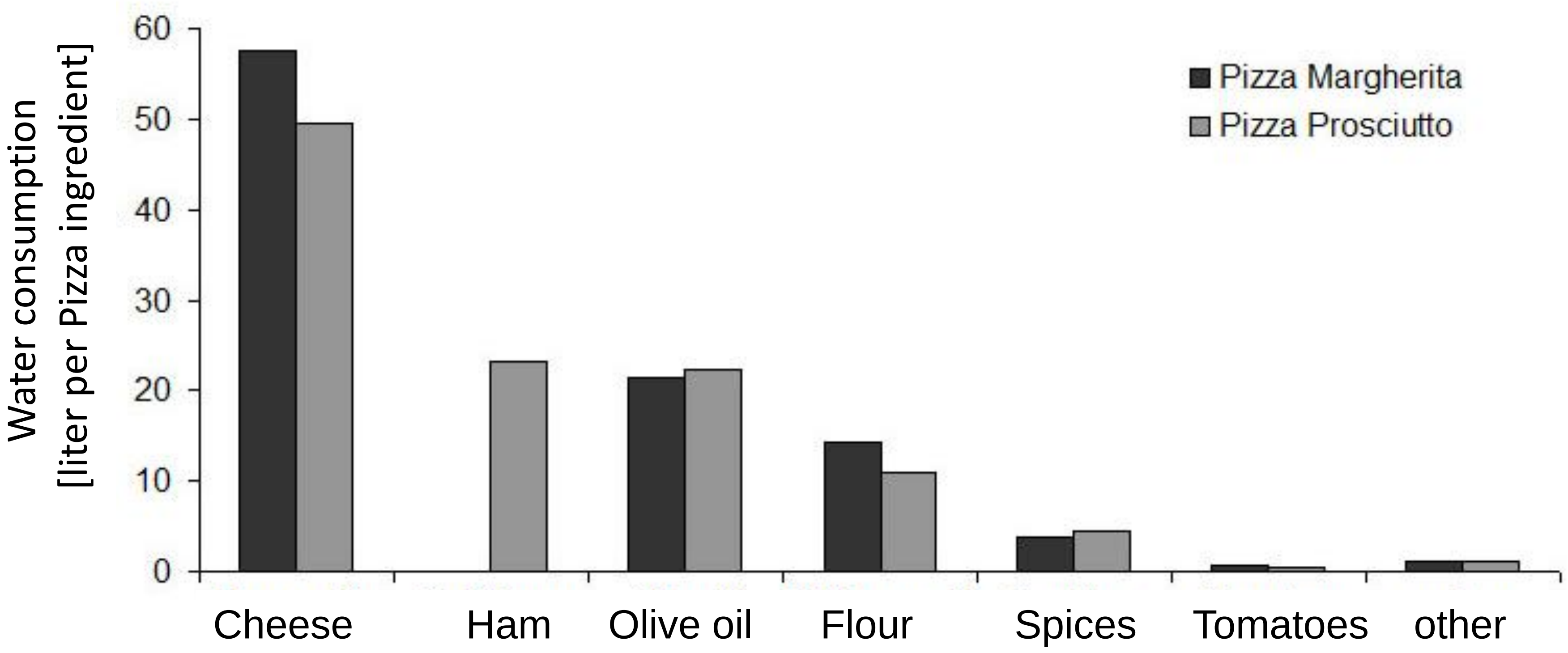
2842 m^3/Cow

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

WATER FOOTPRINT INVENTORY

Ingredients contribution to water consumption of Swiss Pizza



Adapted from *Eymann (2010)*

WATER FOOTPRINT INVENTORY

Data base development

Water Footprint Inventory

Data base development

- **Ecoinvent (ecoinvent center 2007)**

Withdrawal, source, spatial differentiation

No release flow, no quality

Partly regionalized

- **ETH water data (ESD 2012)**

Regionalized

- **Gabi (PE 2010):**

Water input and output,

No quality, some background systems missing (ex: mining)

Partly regionalized

- **GEMStat:** Database for water quality
- **WaterStat (WFN 2012)**

Regionalized

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

Partly 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

WATER FOOTPRINT INVENTORY

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

Water Footprint Inventory

Uncertainties

- Uncertainty
  - Inventory
  - Impact assessment
  - Spatial

Inventory and Impact assessment → Any LCA

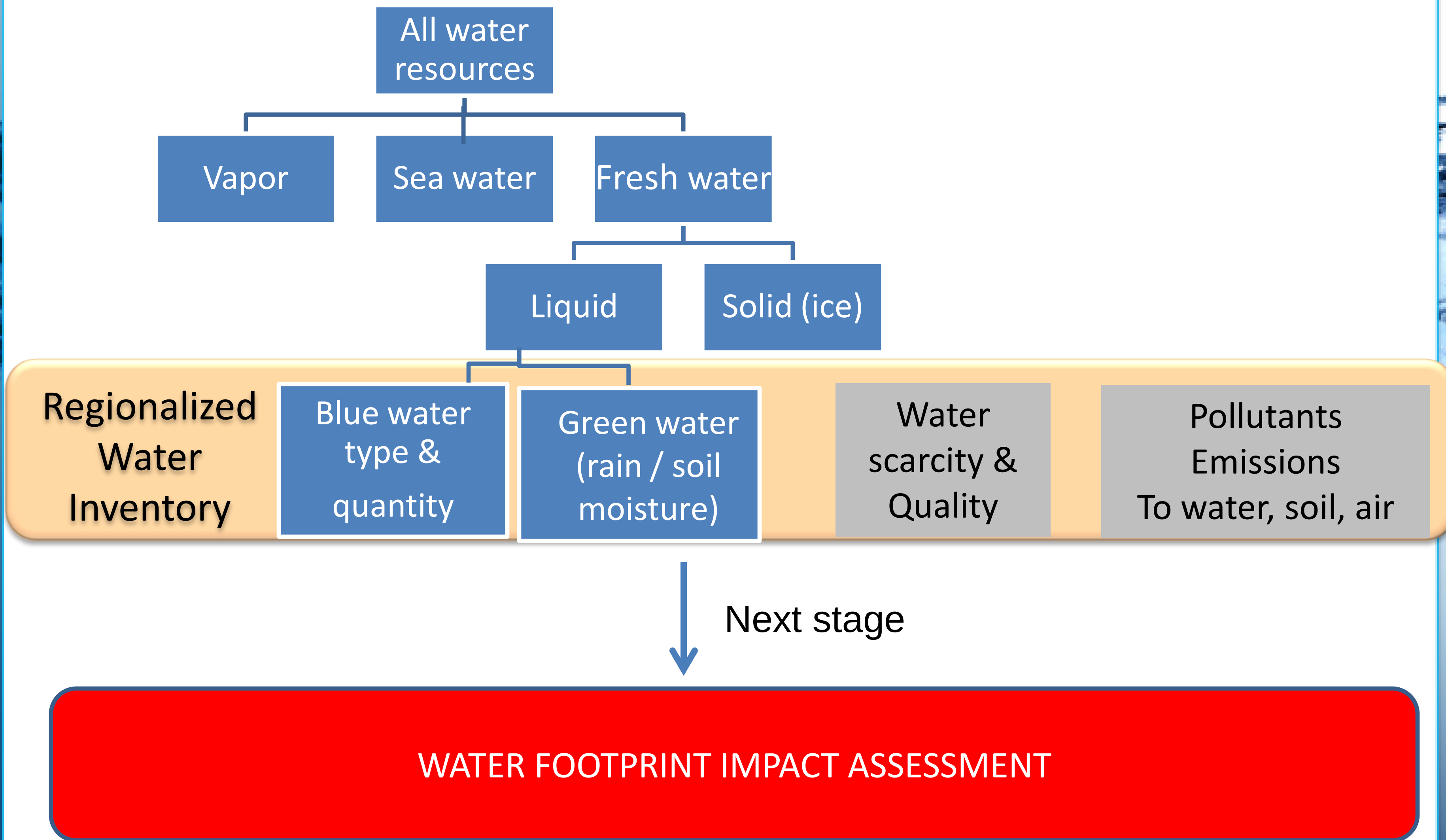
Spatial → Regionalized LCA

- Variability
  - Technology
  - Climate
    - Regional
    - Temporal

Variability → Adds to uncertainty of LCA using spatially aggregated inputs

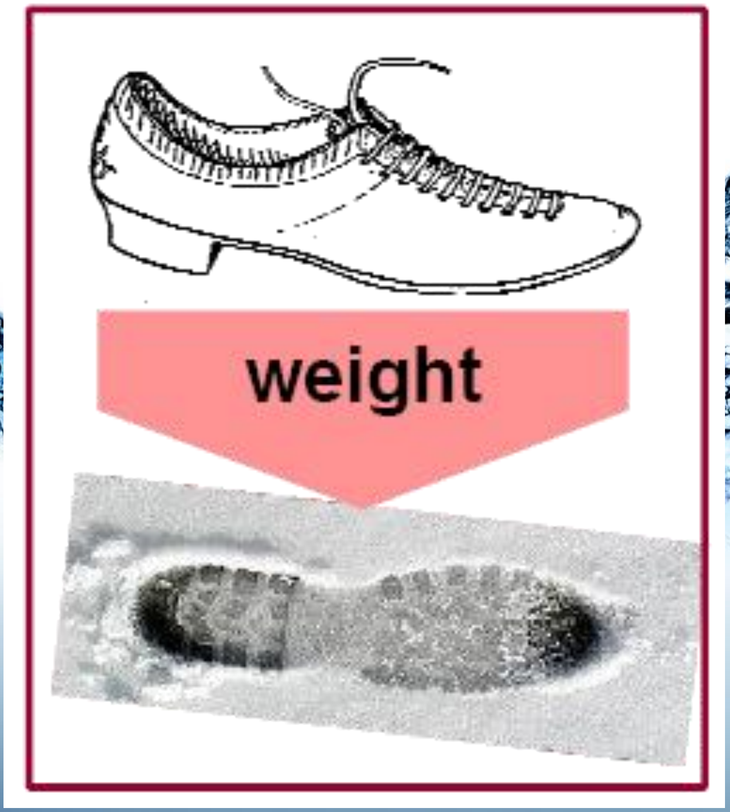
Water Footprint Inventory

Towards impact assessment



BREAK!
20 MIN

IMPACT ASSESSMENT METHODS



METHOD OVERVIEW

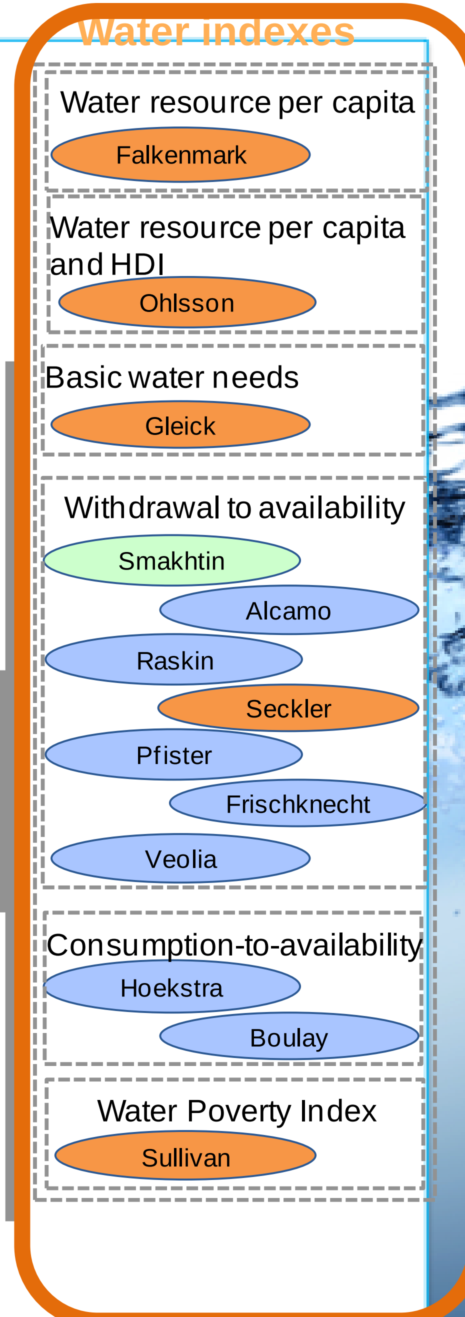
- Water indices and midpoint assessments
  - Water indices
  - Water availability assessment – methods
  - Midpoint impact category assessment methods
  - Examples

- 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



Method / index — Methods or water index addressing water use

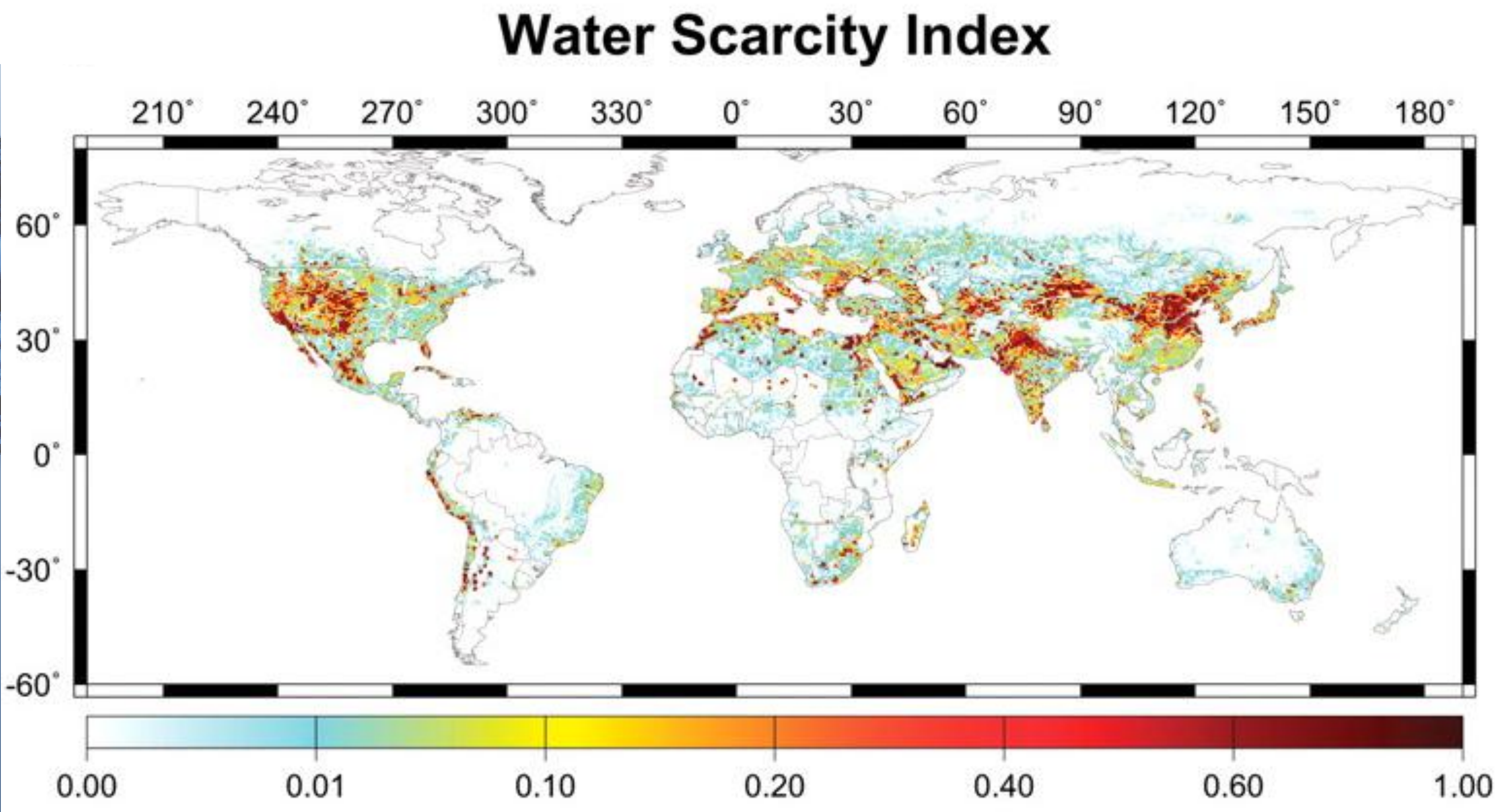
Method — Methods addressing water pollution additionally to water use

Index — Water index *human health* oriented addressing water use

Index — Water index *ecosystem quality* oriented addressing water use

Kounina et al. 2012

USE-TO-AVAILABILITY RATIO (CRITICALITY RATIO)

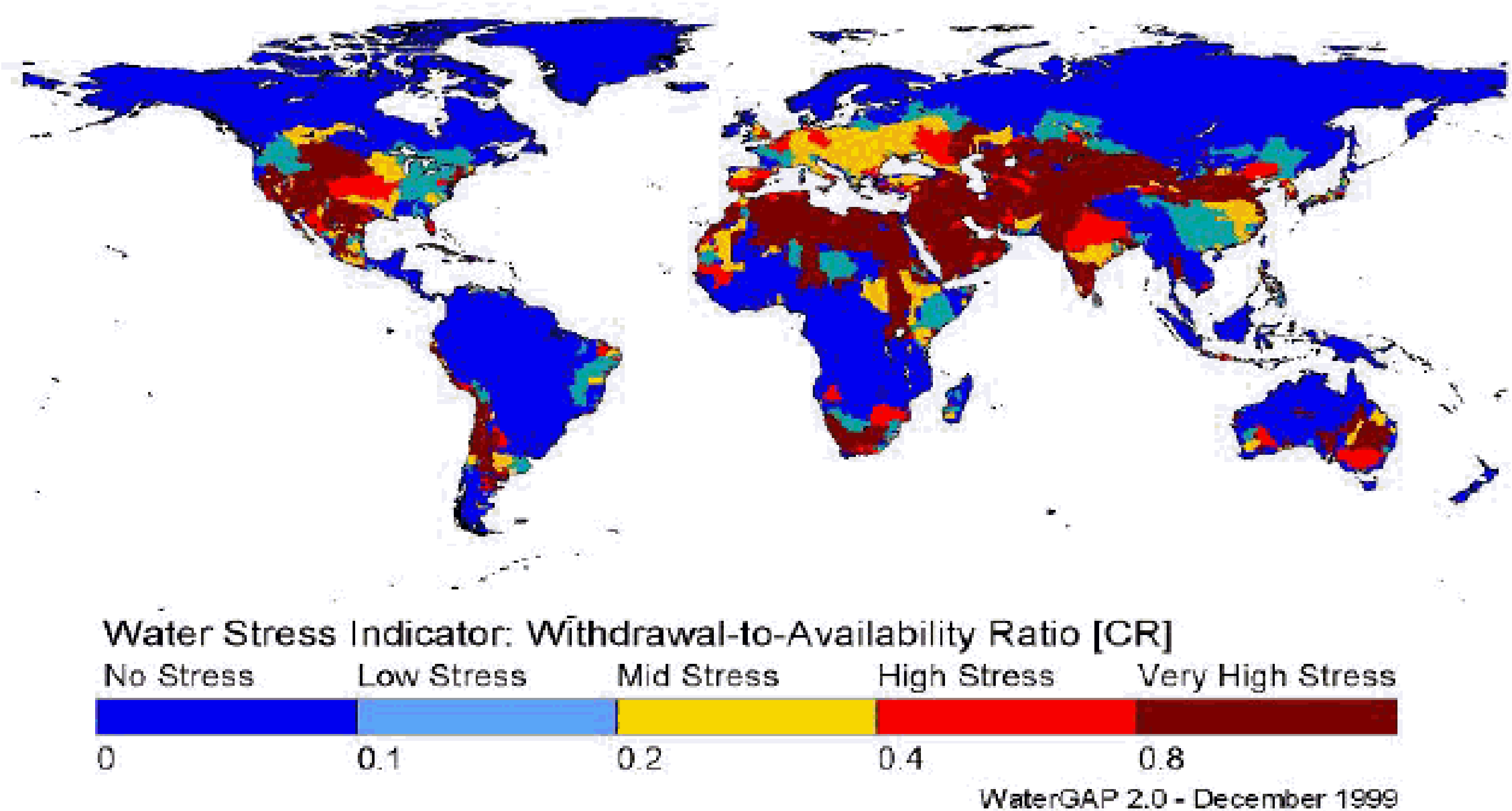


Source: T Oki, S Kanae (2006)

Published by AAAS

USE-TO-AVAILABILITY RATIO (CRITICALITY RATIO)

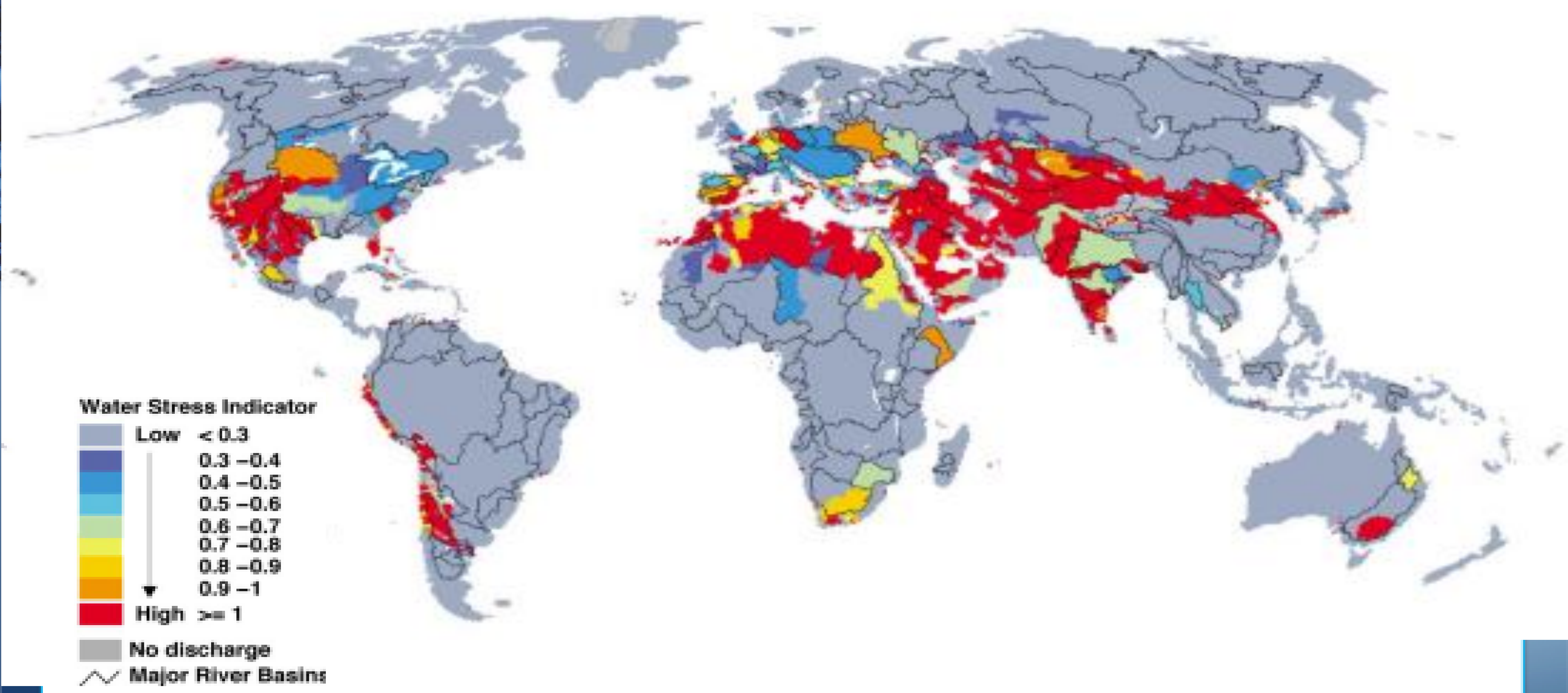
On watershed level: Calibration, upstream/downstream



Source: Alcamo et al. 2000

ENVIRONMENTAL WATER SCARCITY

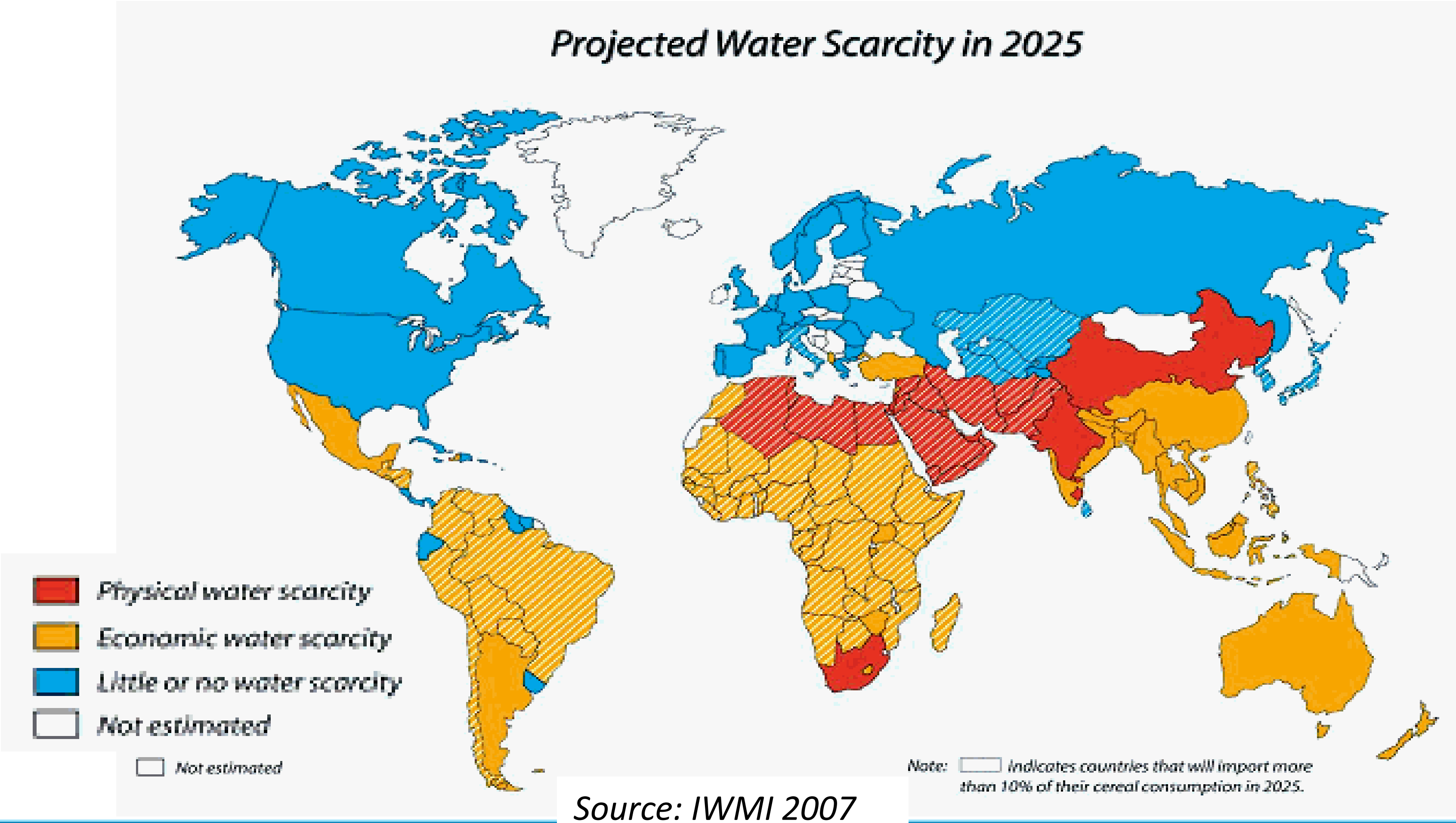
- Includes river flow requirements of ecosystem



Source: Smakthin et al. 2004

IWMI: ECONOMIC WATER SCARCITY

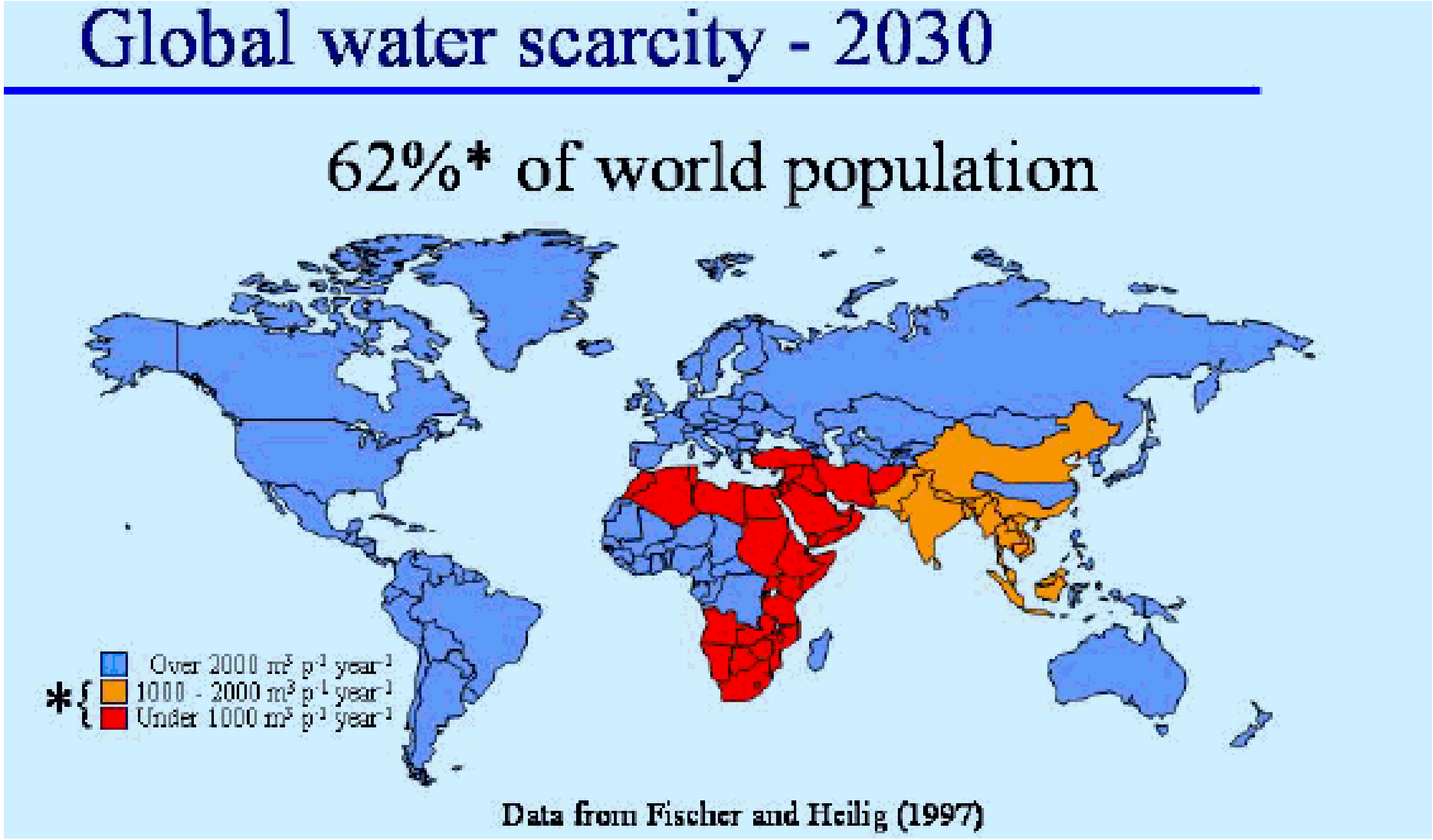
- Includes lack of infrastructure



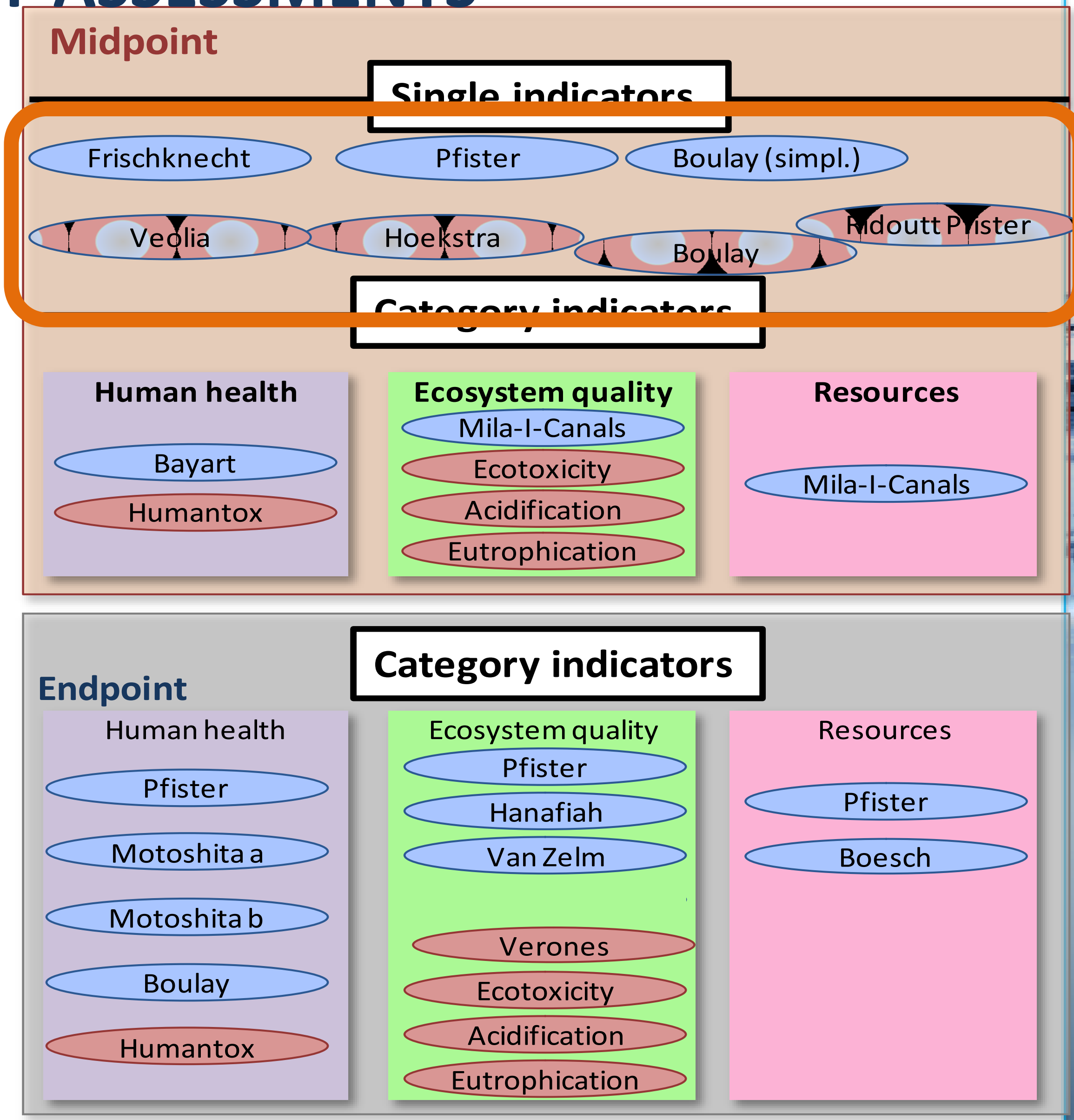
Source: IWMI 2007

FALKENMARK INDEX

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



WATER AVAILABILITY ASSESSMENTS



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

$$\left[\frac{\text{Water use}}{\text{Water availability}}\right]^2 = \left[\frac{\text{Water use}}{\text{Water availability}}\right]^2 \left[\frac{1}{20\%}\right]^2$$

Critical value: 20%

6 classes, 3 orders of magnitude

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

Water scarcity	UBP (points/m3 used)
Low	24
Moderate	220
Medium	880
High	2’400
Very high	6’200
Extreme	22’000

Source: http://www.oebu.ch/oebu/downloads/oekofaktoren_sr28.pdf

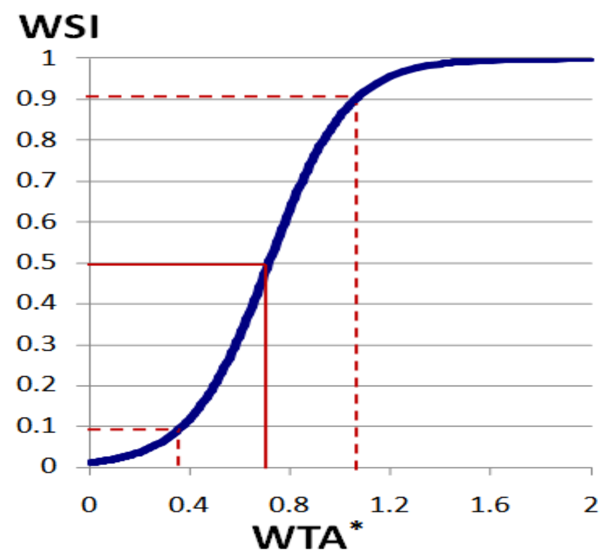
Pfister et al 2009:
Water Stress Index (WSI)

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

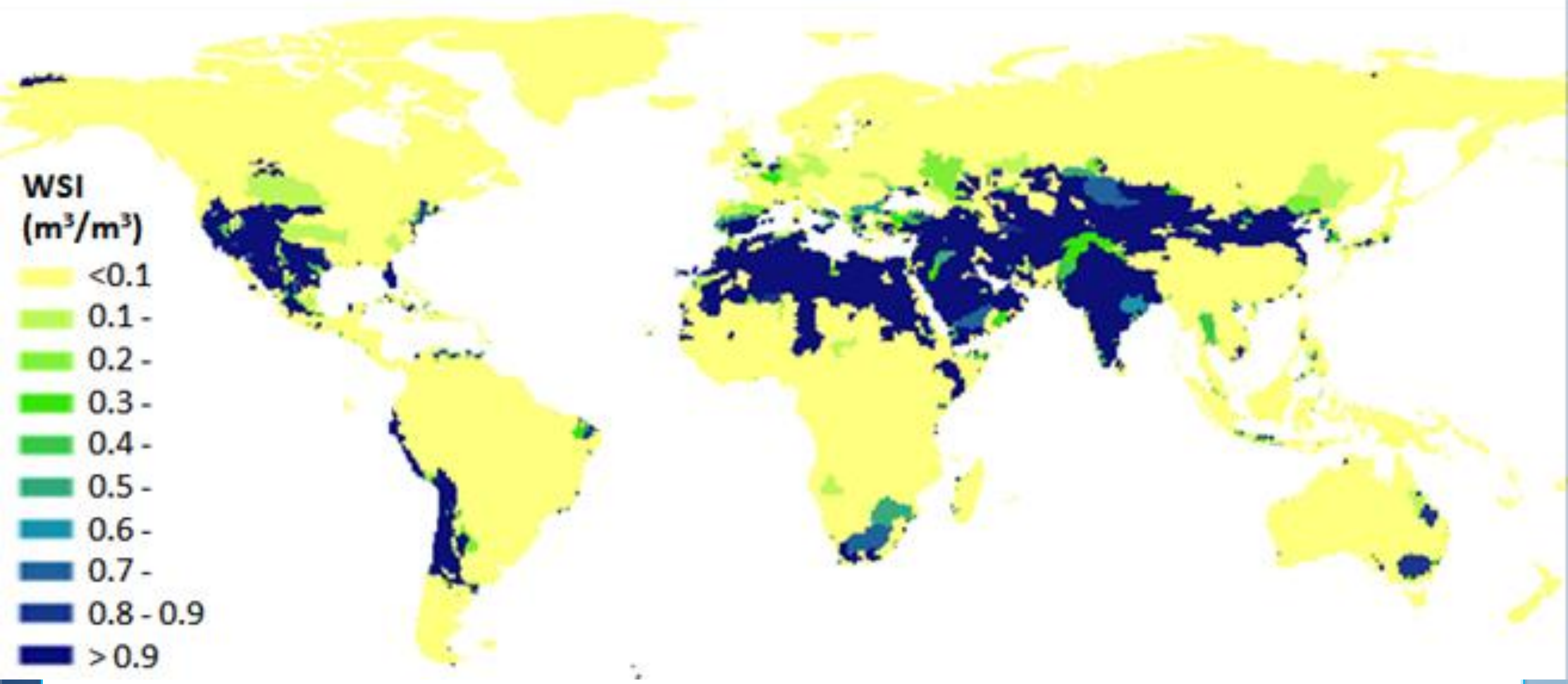
$$WTA^* = \begin{cases} \sqrt{VF} \times WTA & for\ SRF \\ VF \times WTA & for\ non\text{-}SRF \end{cases}$$

- **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

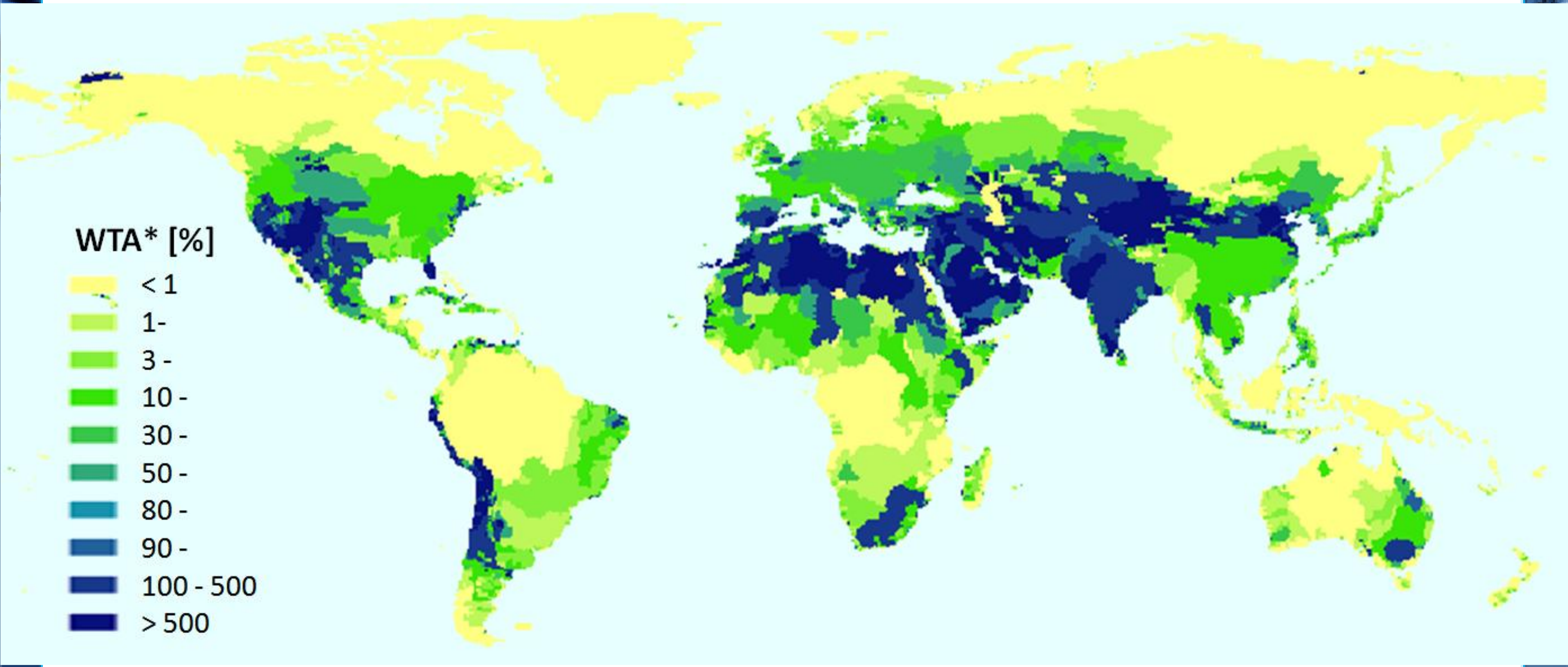


Pfister, Koehler & Hellweg (2009), ES&T 43(11): 4098–4104

FOR MIDPOINT

Water scarcity

WATERSHED



THE WATER IMPACT INDEX, VEOLIA 2011

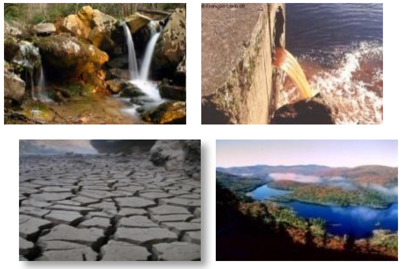
The Water Impact Index accounts for…

… 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 - equival

Following parameters are finally considered :

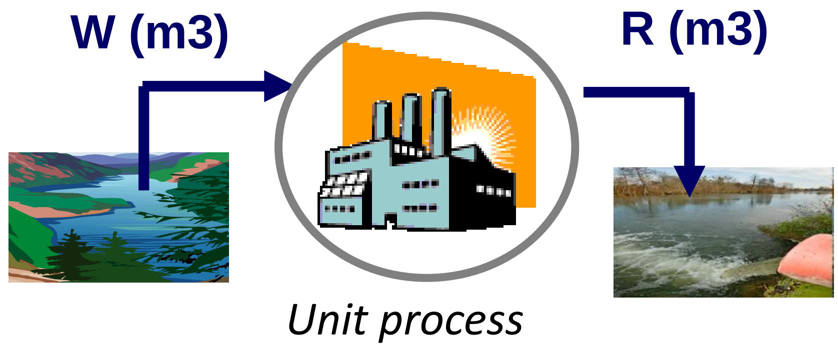
- Volume of water used
  - Water abstracted
  - Water released
- Water quality
  - Water abstracted
  - Water released
- Local hydrological context
  - Freshwater scarcity
- *Resource type*



Veolia Environnement Recherche & Innovation

Bayart et al, LCM 2011

WATER IMPACT INDEX: MODEL



$$\text{Water Impact Index} = \left(W \times Q_w \times WSI_w\right) - \left(R \times Q_R \times WSI_R\right)$$

Volume of water withdrawn / discharged

Quality index

Water scarcity index

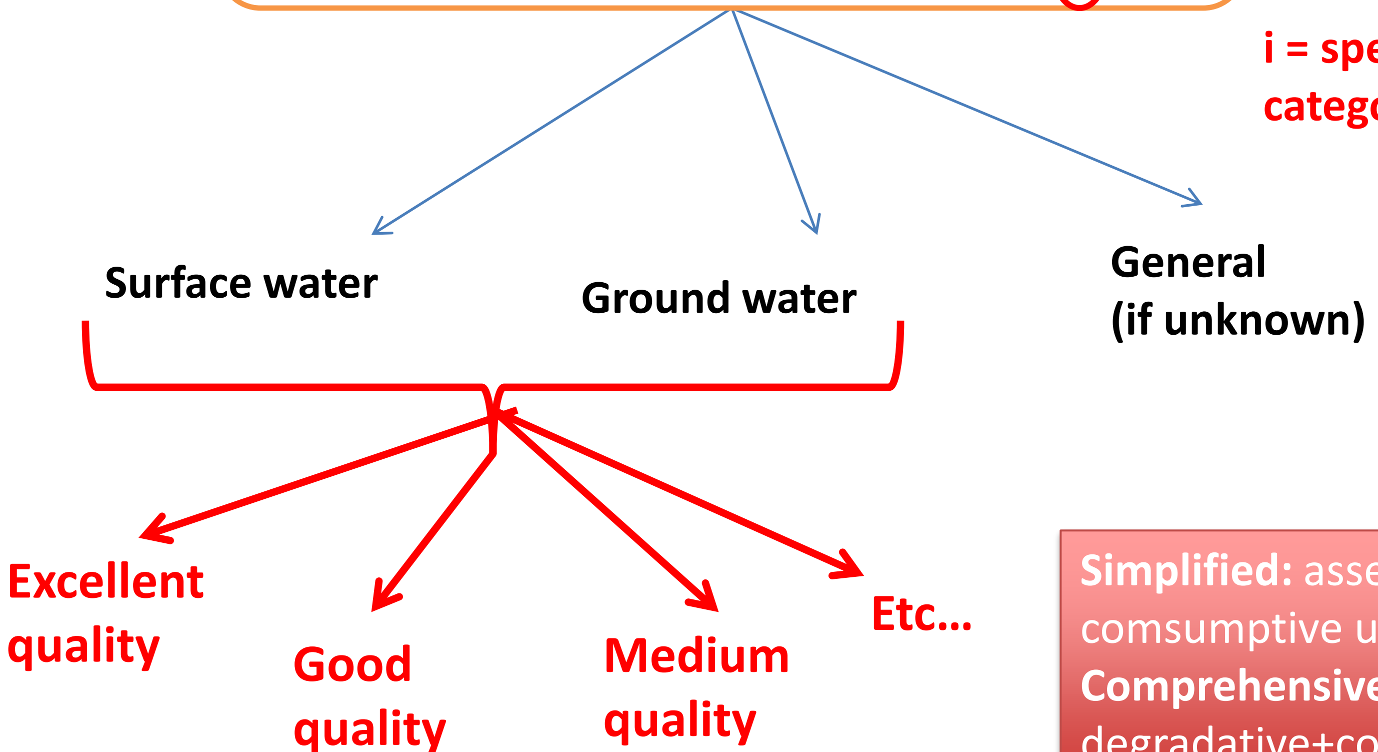
Veolia Environnement Recherche & Innovation

Bayart et al, LCM 2011

Boulay et al: Scarcity Indicator - COMPREHENSIVE

$$\alpha^*_i = \frac{\text{Consumed water}_i}{\text{Available water}^1_i}$$

i = specific water category



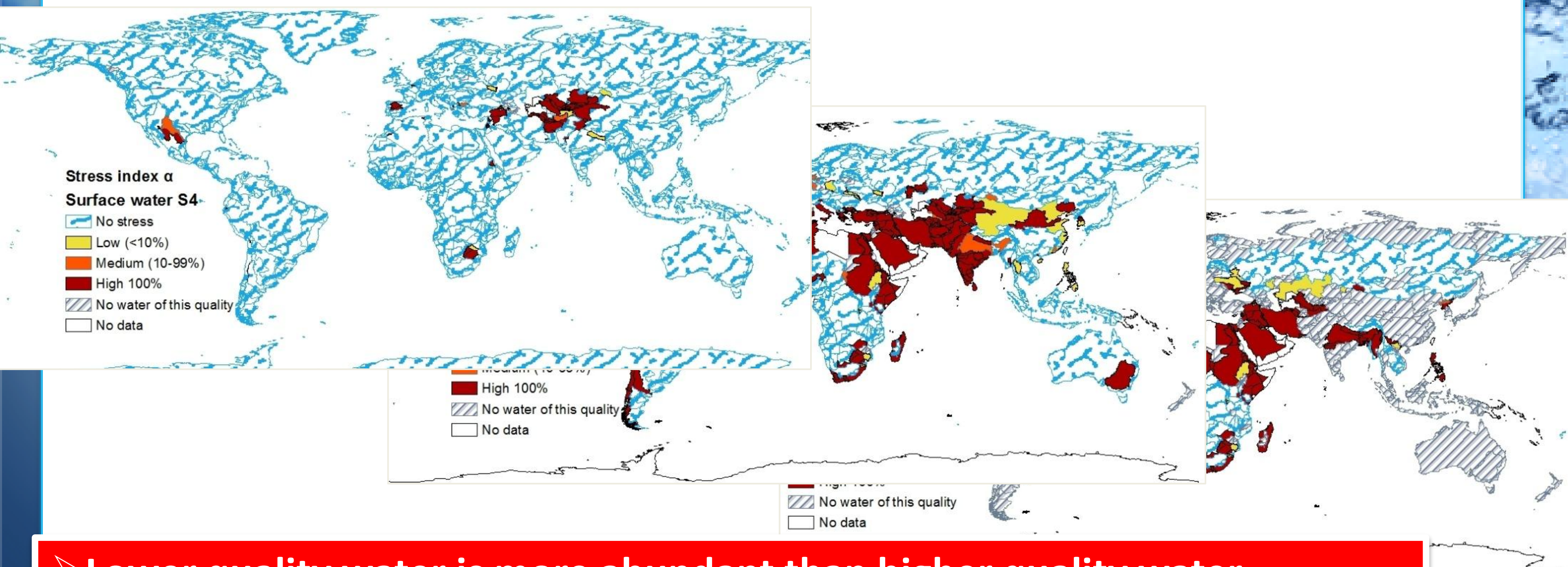
[1] Corrected for Seasonal variations

Simplified: assesses comsumptive use only
Comprehensive: assesses degradative+consumptive use

Boulay et al. (2011), ES&T 45(20): 8948–8957

SCARCITY INDICATOR - COMPREHENSIVE

$$\alpha^* = \frac{\text{Consumed water}}{\text{Available water}^{1}}$$



➢ **Lower quality water is more abundant than higher quality water**

Boulay et al. (2011), ES&T 45(20): 8948–8957

BOULAY ET AL: MODELING OF AVAILABILITY INDICATOR

- **α is modelled from α ***
- **Indicator between 0 and 1**
- **Based on accepted water stress thresholds:**
  - Low → Set to 0
  - Medium } S-Curve
  - high } in between
  - very high → Set to 1

→ consumption of 1 m^3 of water will not affect other users when water is abundant

→ 1 m3 of water consumed will eventually deprive other competing users of 1 m3

Boulay et al. (2011), ES&T 45(20): 8948–8957

IMPACT ASSESSMENT

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

CF is the availability indicator α

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

Water Category i_{in}

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

Water Category i_{out}

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

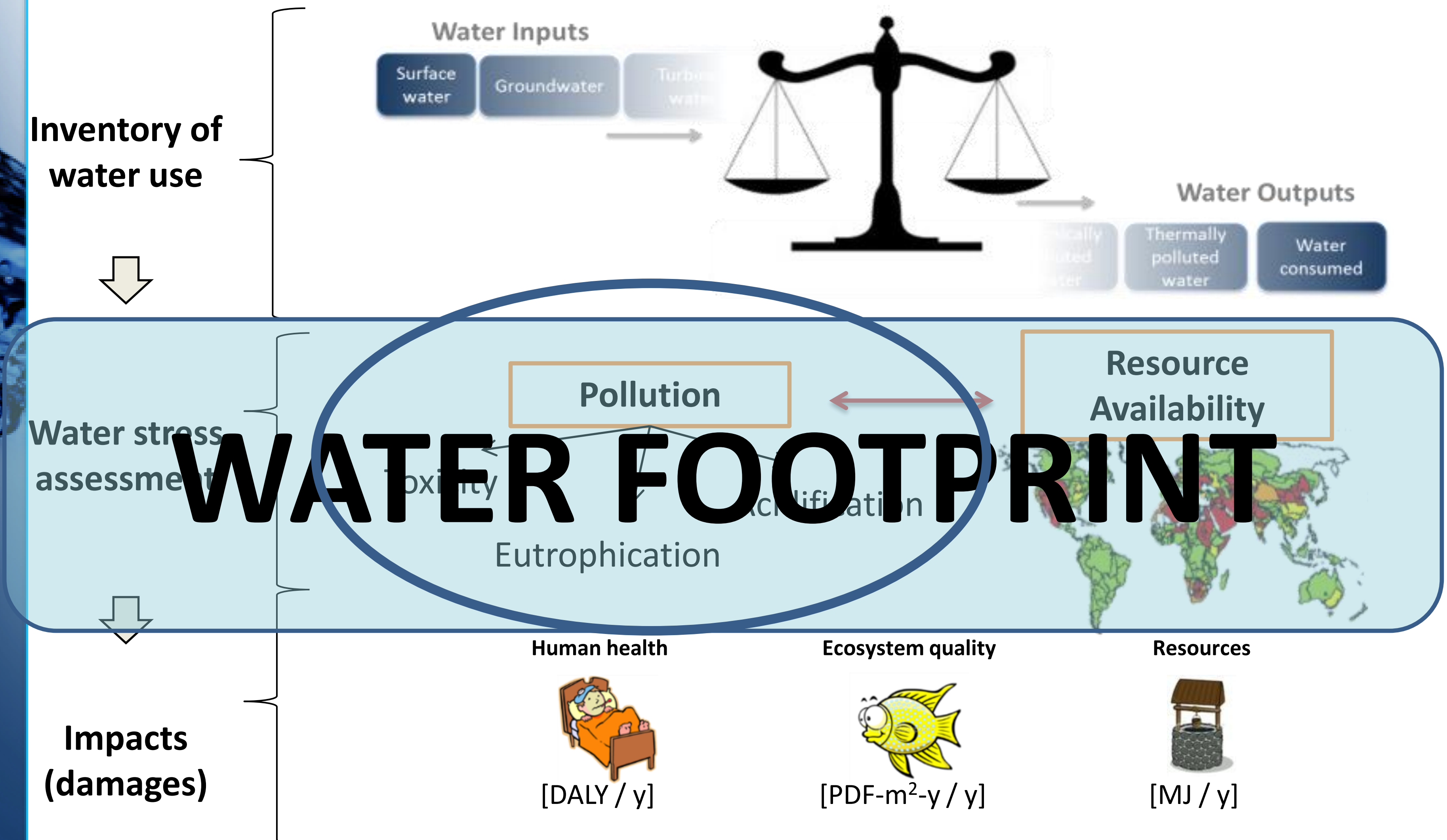
Note: CF= Characterization Factor

Boulay et al. (2011), ES&T 45(20): 8948–8957

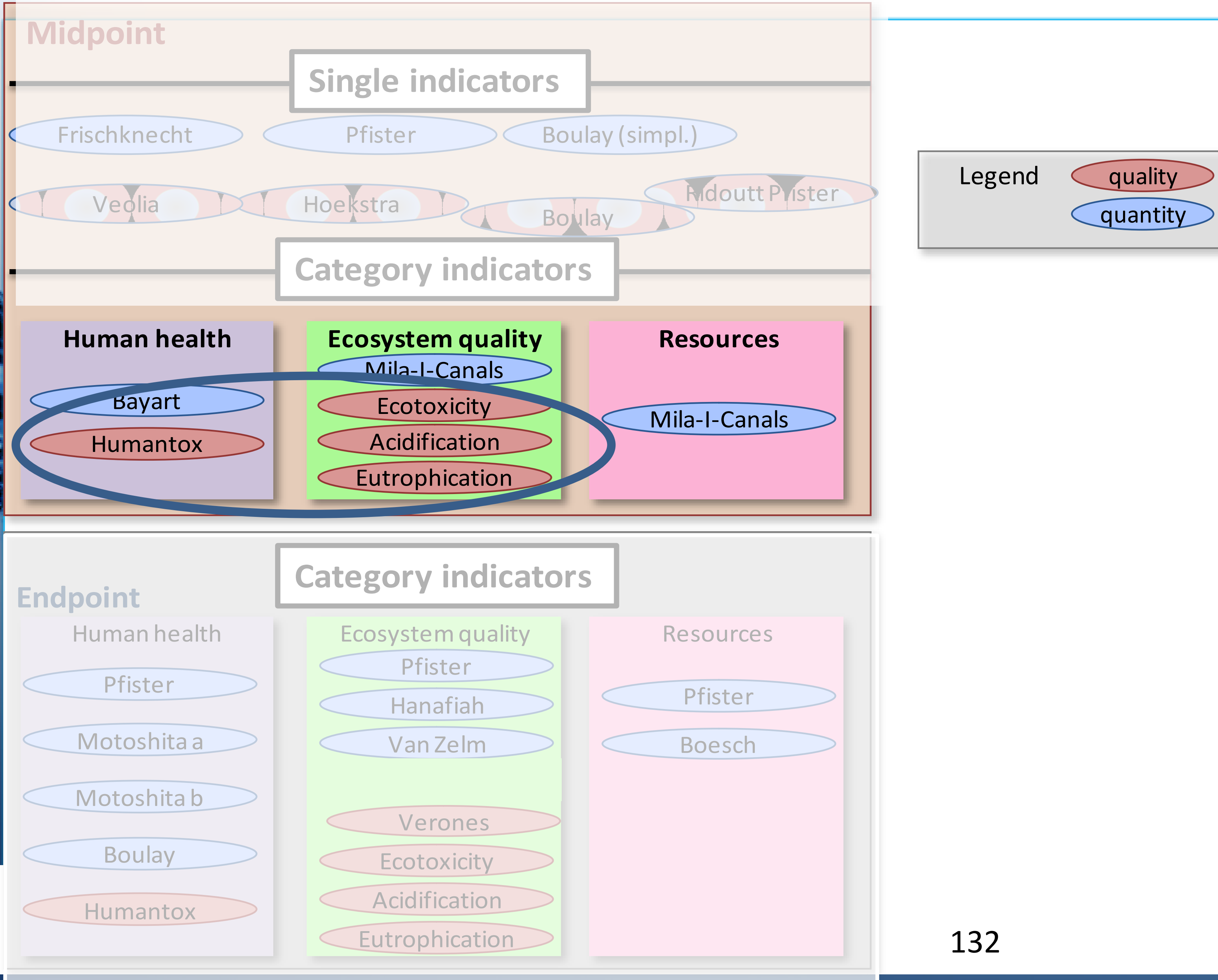
Quality integration for Water Footprint as stand-alone indicator

- 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…



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


Midpoint
Single indicators
Frischknecht
Pfister
Boulay (simpl.)
Veolia
Hoekstra
Boulay
Ridoutt Pfister
Category indicators
Human health
Bayart
Humantox
Ecosystem quality
Mila-I-Canals
Ecotoxicity
Acidification
Eutrophication
Resources
Mila-I-Canals
Endpoint
Category indicators
Human health
Pfister
Motoshita a
Motoshita b
Boulay
Humantox
Ecosystem quality
Pfister
Hanafiah
Van Zelm
Verones
Ecotoxicity
Acidification
Eutrophication
Resources
Pfister
Boesch
Legend
quality
quantity

Human health

Bayart

Humantox

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)

Ecosystem quality

Mila-I-Canals

Ecotoxicity

Acidification

Eutrophication

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 devlopments 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

Ecosystem quality

Mila-I-Canals

Ecotoxicity

Acidification

Eutrophication

ECOTOXICITY

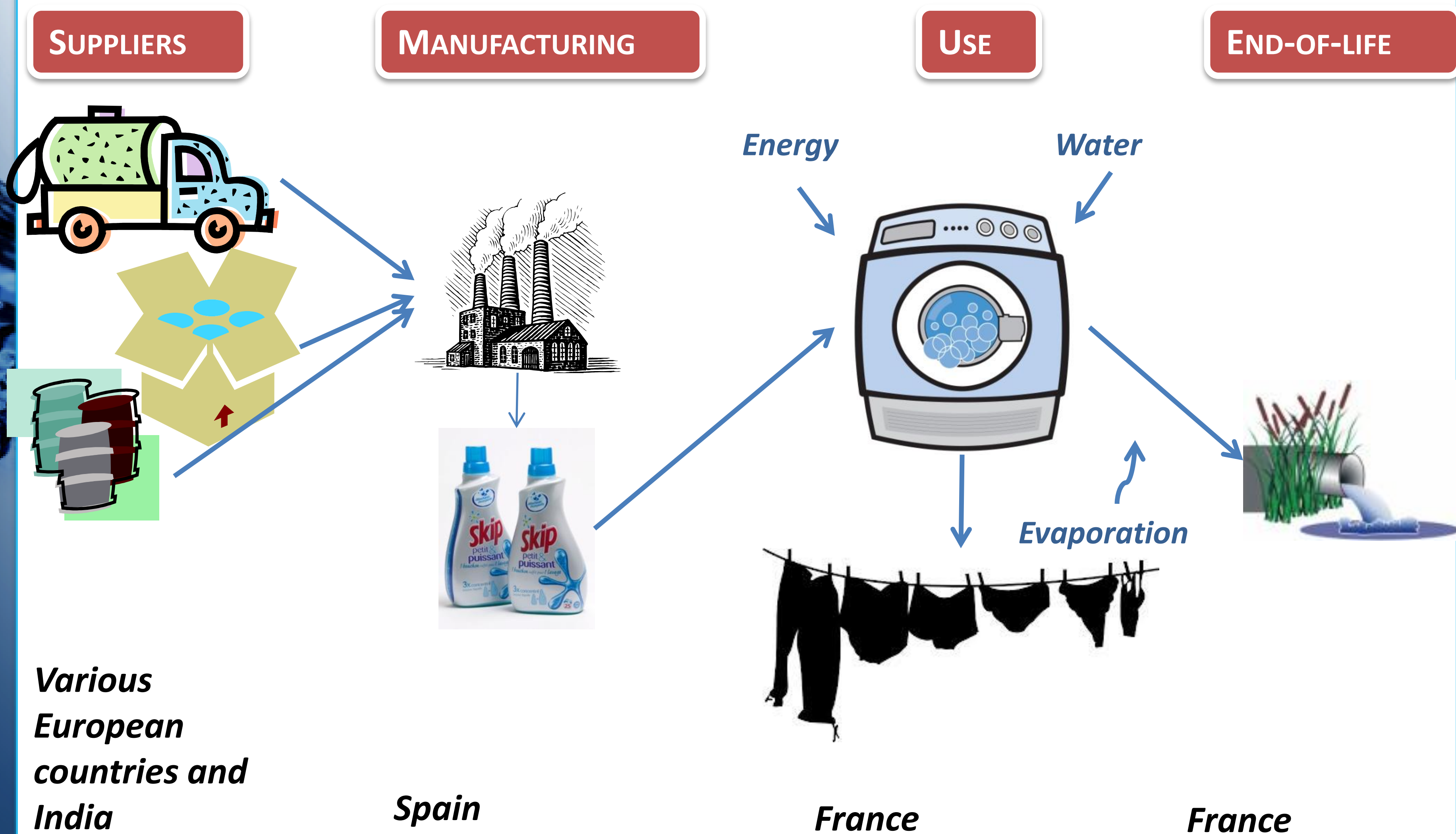
USETOX (ROSENBAUM ET AL. 2008)

- **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

Water Footprint of a Load of Laundry



Boulay, A.-M., Bayart, J.-B., Bulle, C., Franceschini, H., Motoshita, M., Muñoz, I., Pfister, S., et al. (2013). Water impact assessment methods analysis (Part B): Applicability for water footprinting and decision making with a laundry case study. *International Journal of Life Cycle Assessment, Submitted.*

METHODOLOGY OVERVIEW - MIDPOINT

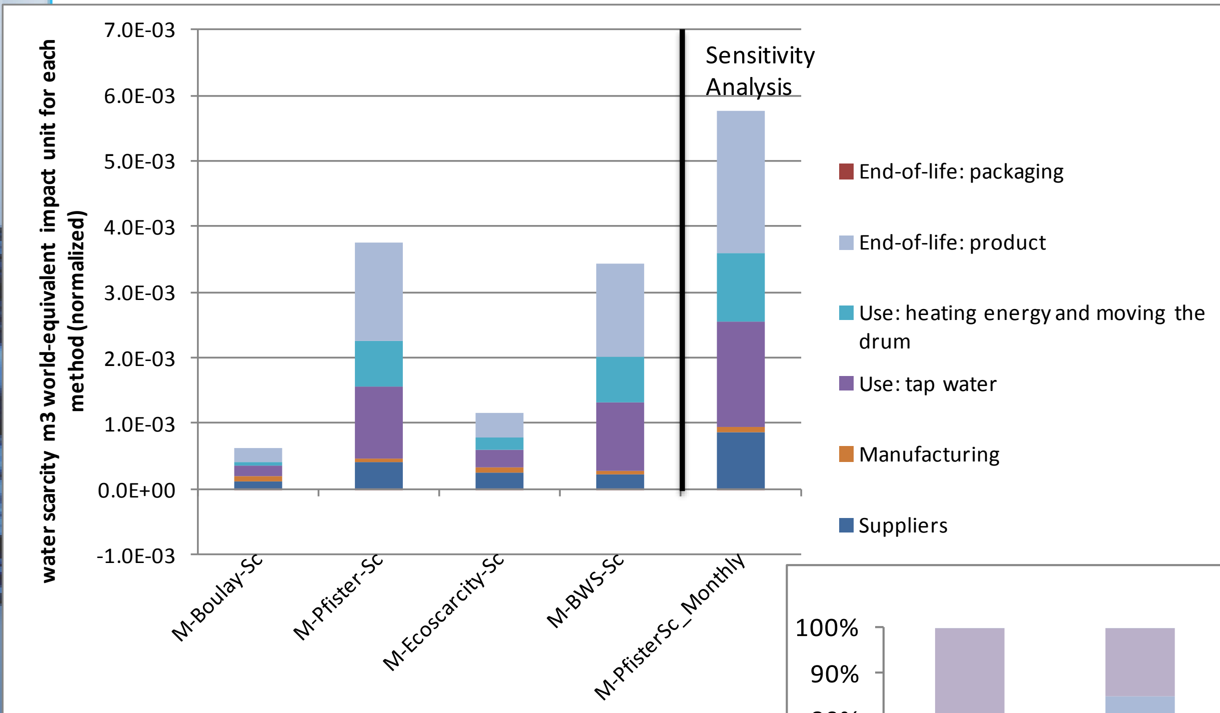
Water Footprint profile at midpoint: Water availability and water degradation

	Indicator	Reference
	Water Availability	
1	Scarcity	Pfister et al.
1		Boulay et al.
1		Swiss Eco-Scarcity
1		WFN, Hoekstra et al.
1a	Availability	Boulay et al.
1a		Veolia Impact Index, Bayart el al.
	Water Degradation	
2	Eutrophication	ReCIPe
3	Acidification	Impact 2002+
4	Ecotoxicity	Usetox
5	Human Toxicity	Usetox

→Only one method needed

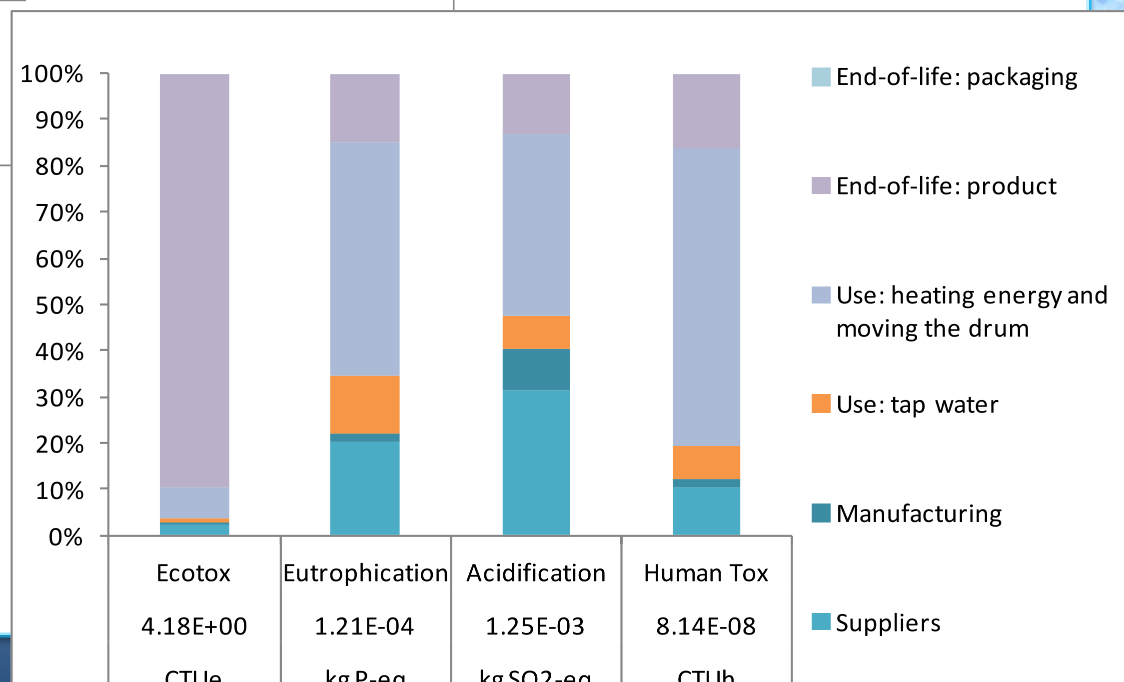
Boulay, A.-M., Bayart, J.-B., Bulle, C., Franceschini, H., Motoshita, M., Muñoz, I., Pfister, S., et al. (2013). Water impact assessment methods analysis (Part B): Applicability for water footprinting and decision making with a laundry case study. *International Journal of Life Cycle Assessment, Submitted*.

Midpoint Water Footprint profile

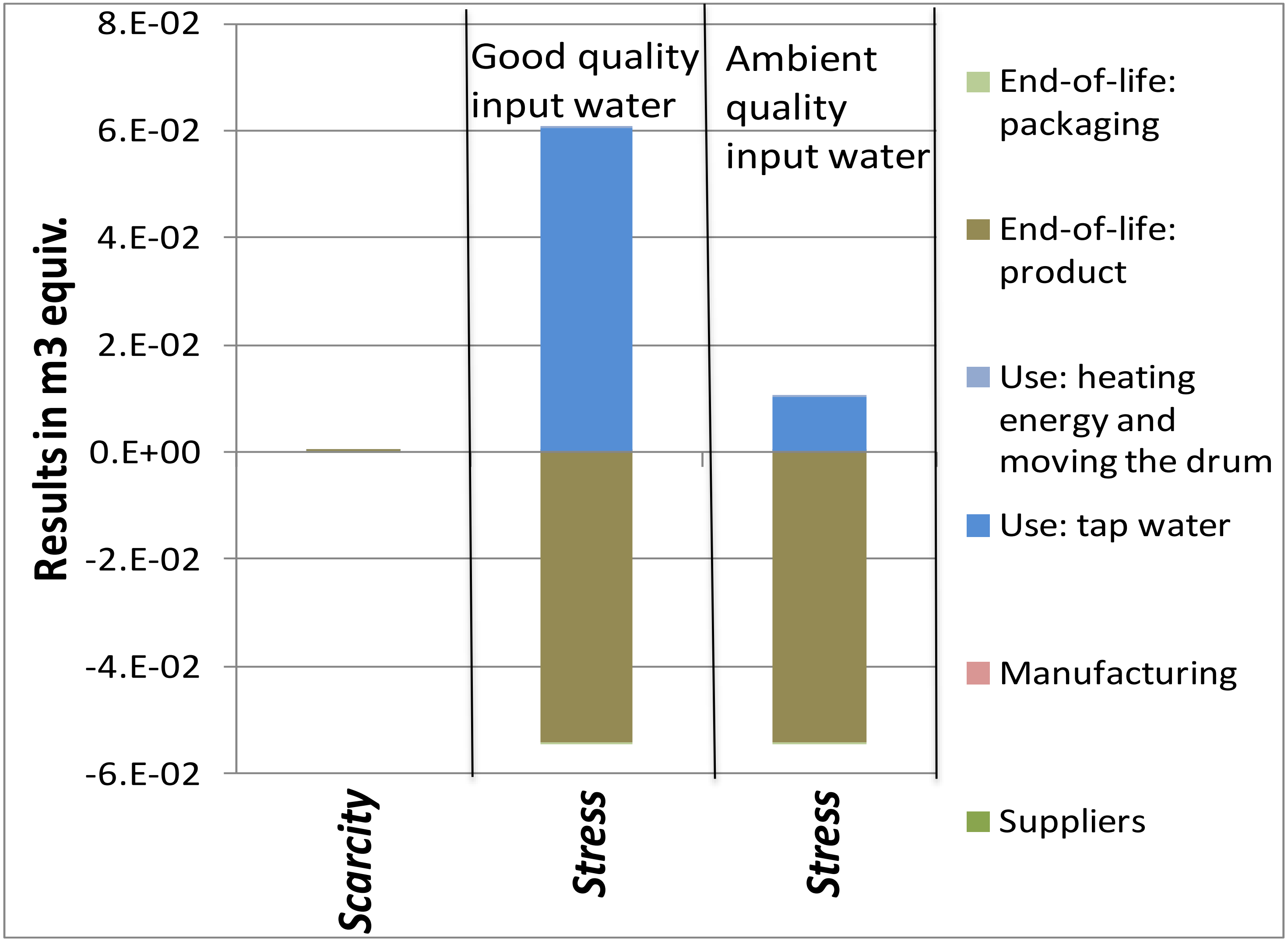


Water Scarcity indicators

Water degradation indicators



SCARCITY VS STRESS



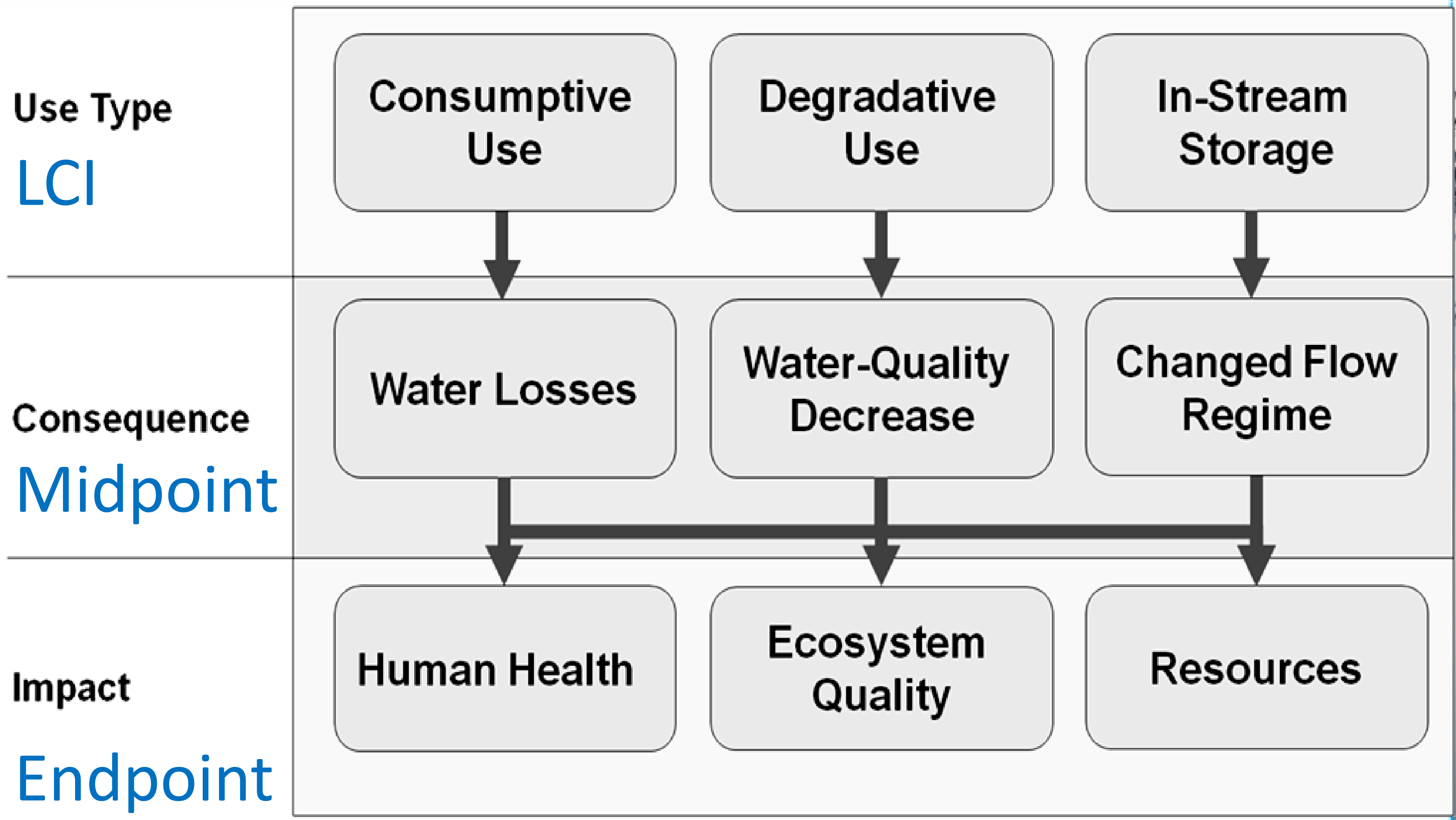
Boulay, A.-M., Bayart, J.-B., Bulle, C., Franceschini, H., Motoshita, M., Muñoz, I., Pfister, S., et al. (2013). Water impact assessment methods analysis (Part B): Applicability for water footprinting and decision making with a laundry case study. *International Journal of Life Cycle Assessment*, *Submitted*.

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

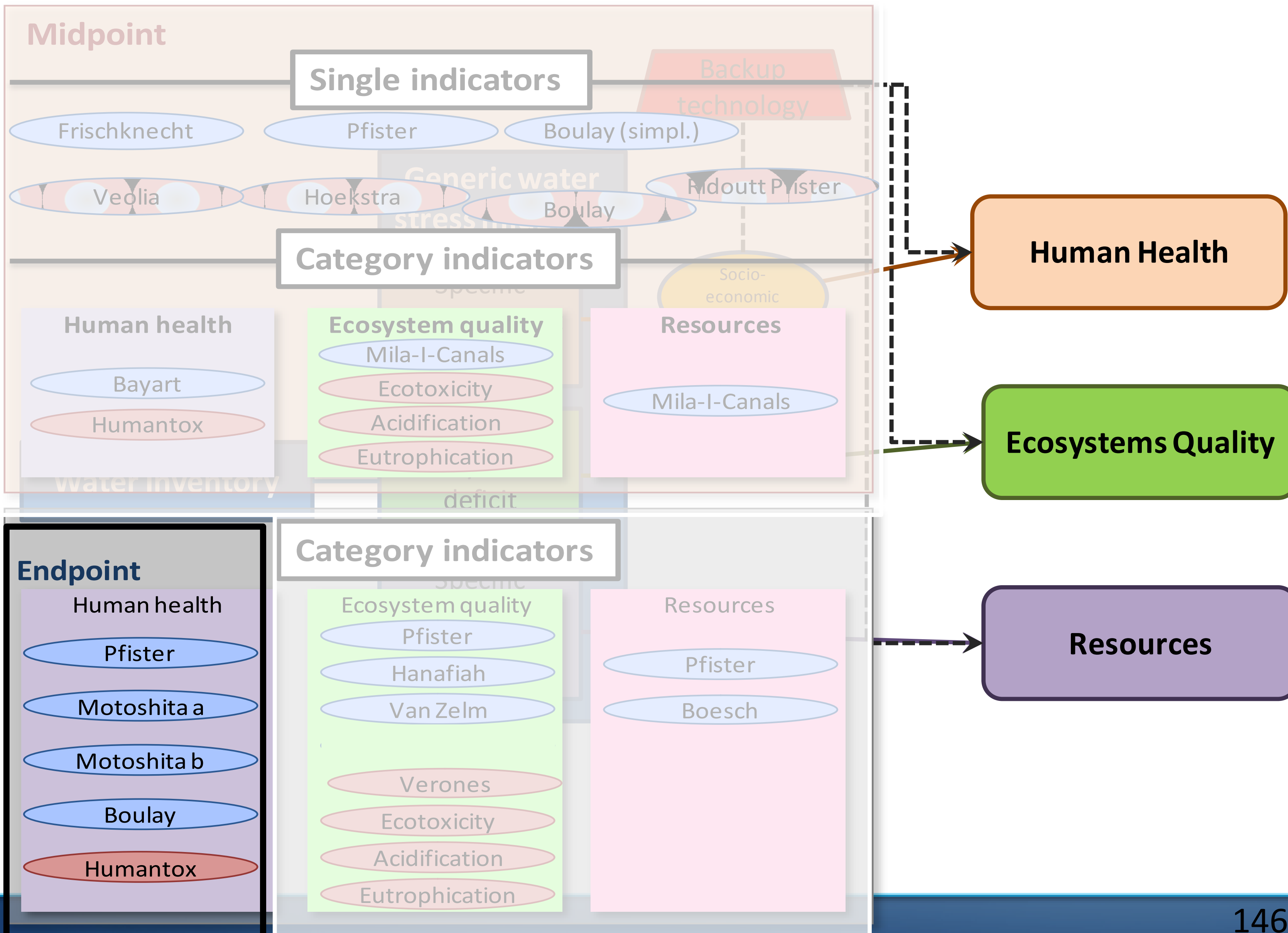
ENDPOINT ASSESSMENT (ENVIRONMENTAL IMPACTS)

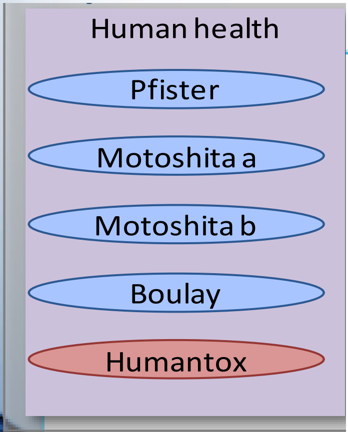
LCIA METHODS FOR WATER USE



Pfister, Koehler & Hellweg (2009), ES&T 43(11): 4098–4104

WATER IMPACTS ENDPOINT MODELING





Human Health

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).

Pfister et al 2009: Impacts on human health

Main pathway is malnutrition due to lack of freshwater and diminished agricultural yields

$$\Delta HH_{malnutrition,i} = \underbrace{\underbrace{WSI_i \cdot WU_{\%agriculture,i}}_{WDF_i} \cdot \underbrace{HDF_{malnutrition,i} \cdot WR_{malnutrition}^{-1}}_{EF_i} \cdot DF_{malnutrition}}_{CF_{malnutrition,i}} \cdot WU_{consumptive,i}$$

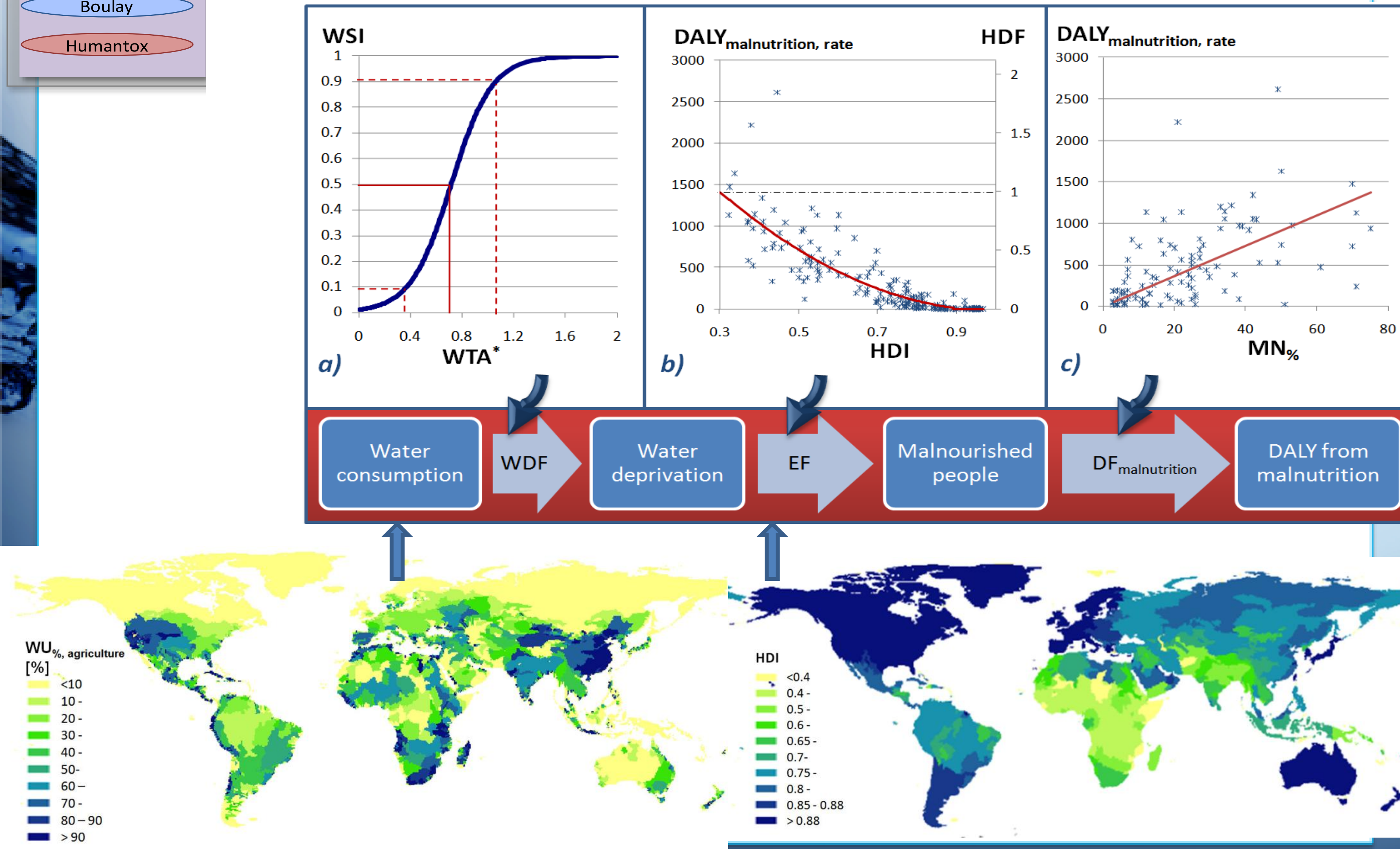
$HH_{malnutrition,\,i}$: human health damage (DALY)
WSI: physical water stress index (-)
$WU_{\%agriculture}$: fraction of agricultural water use (-)
WDF_i: water deprivation factor (m3 deprived/m3 consumed)
$HDF_{malnutrition,i}$: human development factor (-)
$WR_{malnutrition}$: per-capita water requirement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

Pfister, et al.(2009), ES&T 43(11): 4098–4104

Human health

- Pfister
- Motoshita a
- Motoshita b
- Boulay
- Humantox

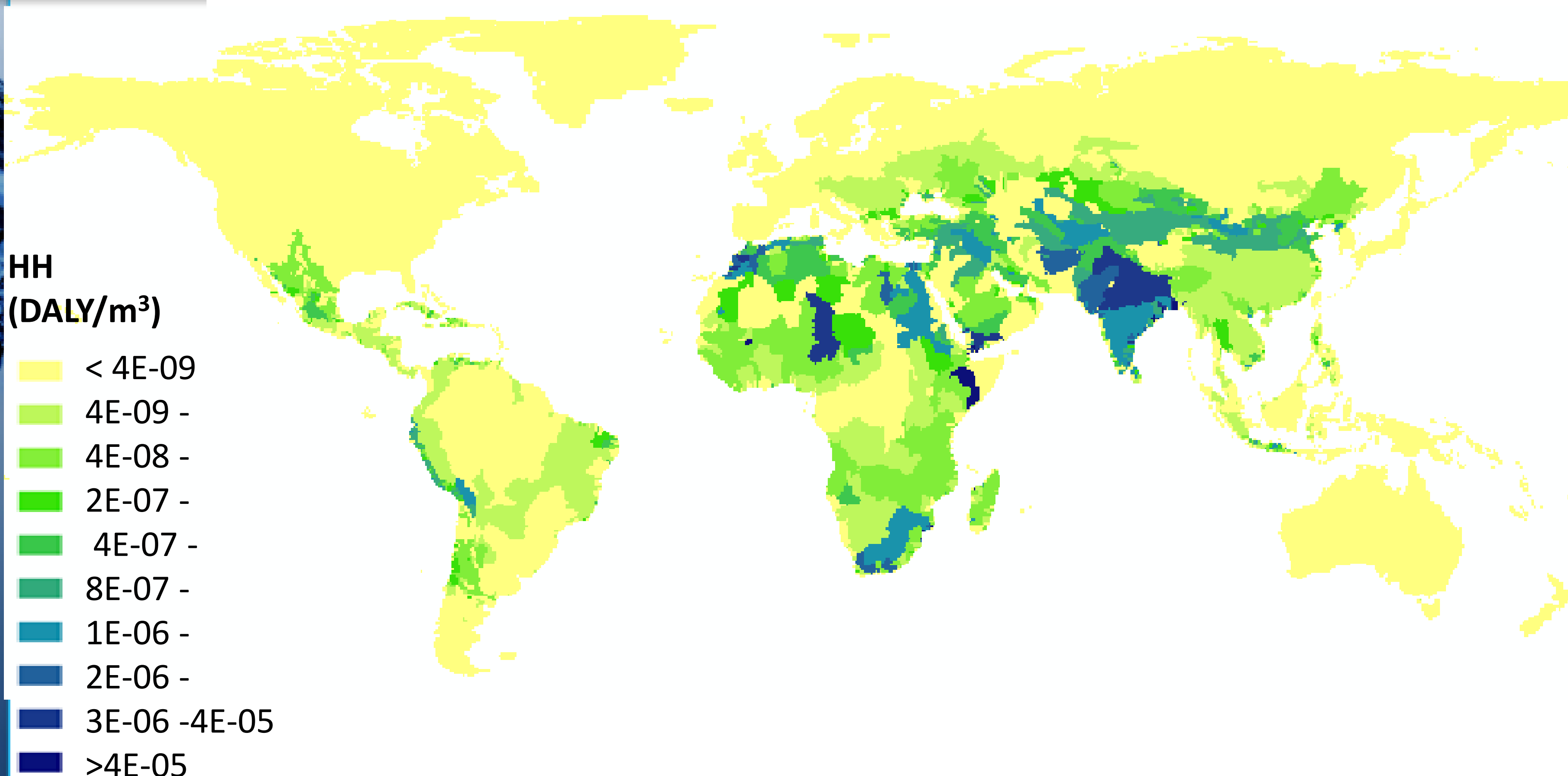
PFISTER ET AL 2009: IMPACTS ON HUMAN HEALTH



Pfister et al.(2009)

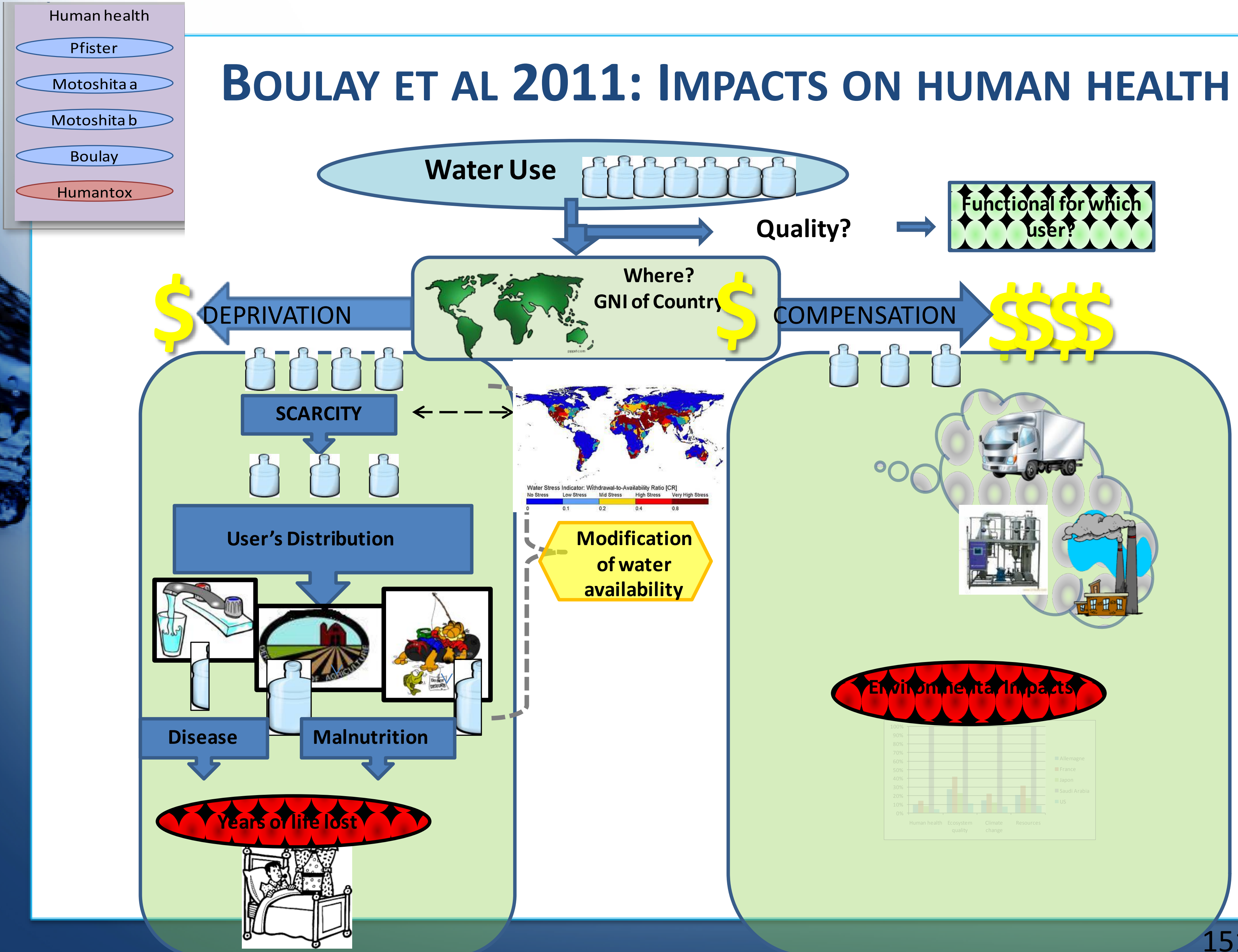
Human health
Pfister
Motoshita a
Motoshita b
Boulay
Humantox

PFISTER ET AL 2009: IMPACTS ON HUMAN HEALTH



Pfister et al.(2009)

BOULAY ET AL 2011: IMPACTS ON HUMAN HEALTH



Human health

- Pfister
- Motoshita a
- Motoshita b
- Boulay
- Humantox

BOULAY ET AL 2011: IMPACT ASSESSMENT

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

Specific Characterization Factors in DALY/m³

-Volume V_{in}	-Volume V_{out}
-**Source** } **Water Category i_{in}**	-**Source** } **Water Category i_{out}**
-**Quality**	-**Quality**
-CF_{in}	-CF_{out}

Impact = (Volume$_{in}$ x CF$_{in}$)- (Volume$_{out}$ x CF$_{out}$)

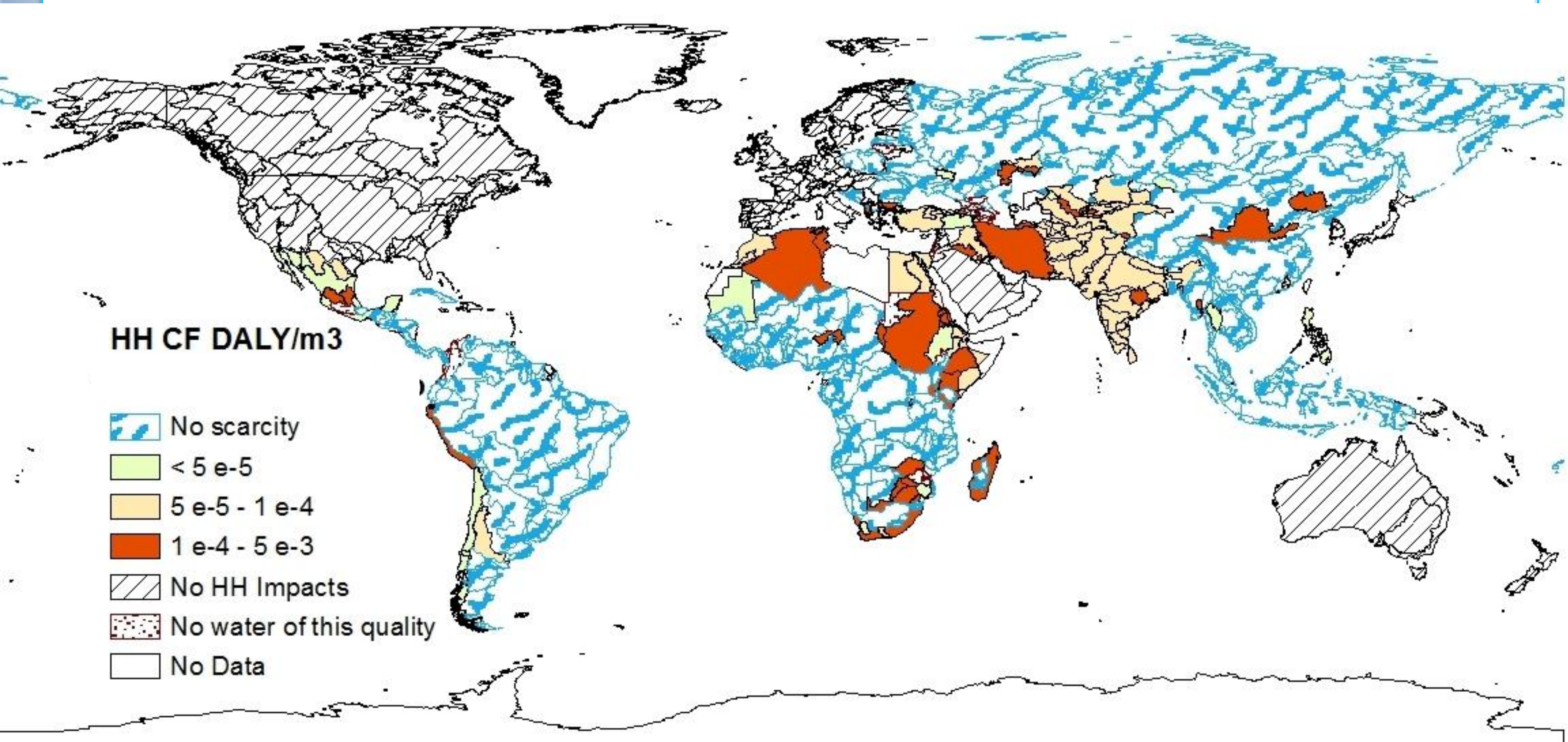
$$\text{Impact} = (\text{Volume}_{in} \times CF_{in}) - (\text{Volume}_{out} \times CF_{out})$$

Note: CF= Characterization Factor

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

Boulay et al: Impacts on human health

Characterization Factors in Daly/m³ for average quality water



Human health

Pfister

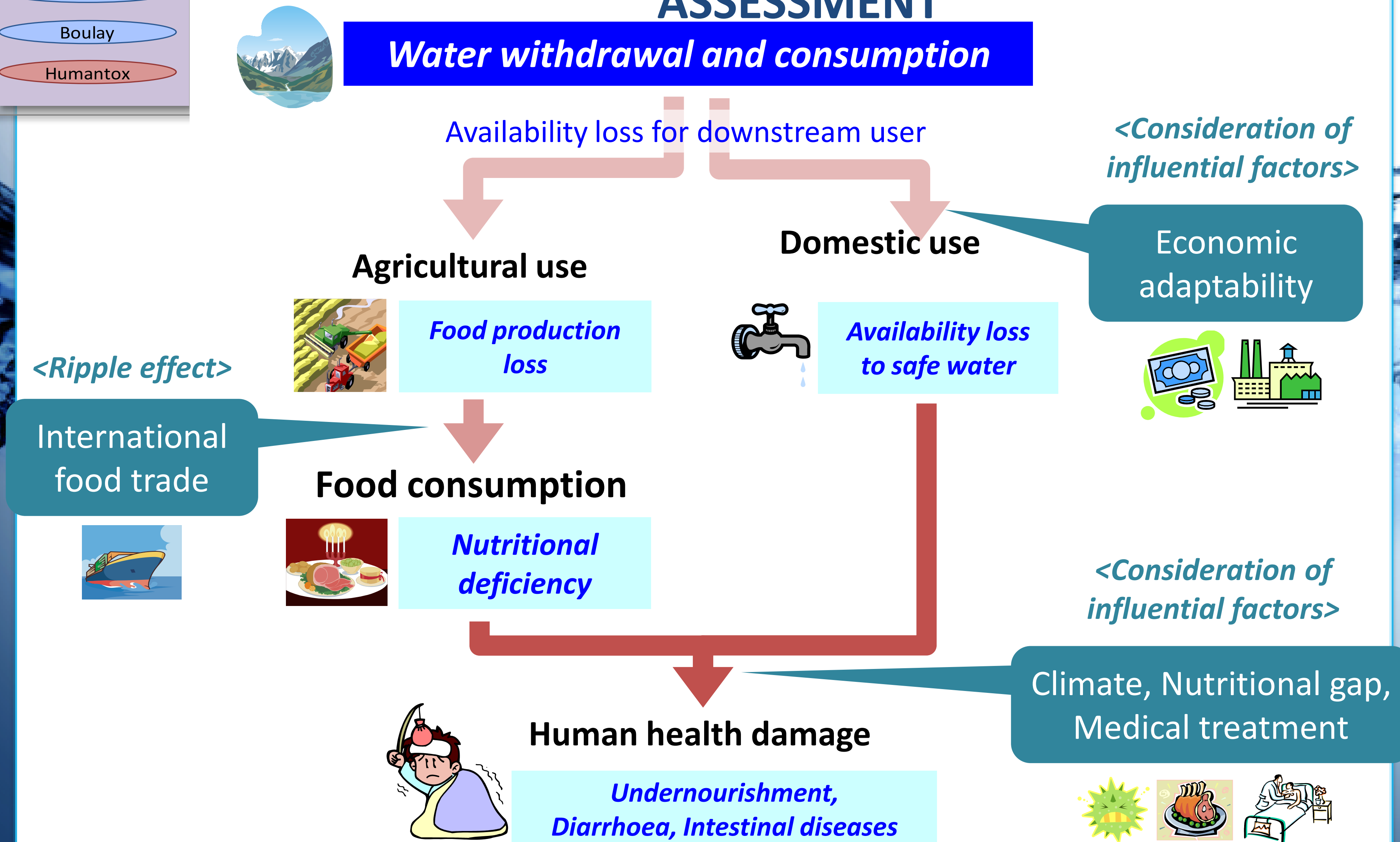
Motoshita a

Motoshita b

Boulay

Humantox

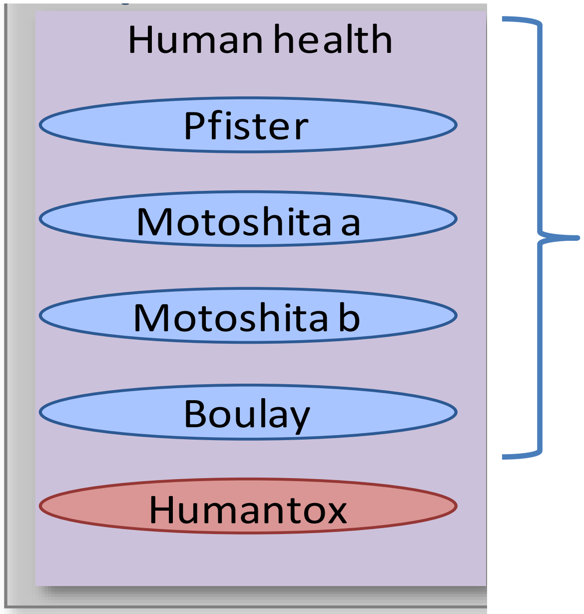
MOTOSHITA ET AL. 2010: HUMAN HEALTH DAMAGE ASSESSMENT



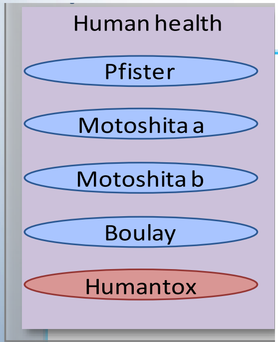
Motoshita et al 2010a/b

Statistical modeling on country scale

IMPORTANT NOTE



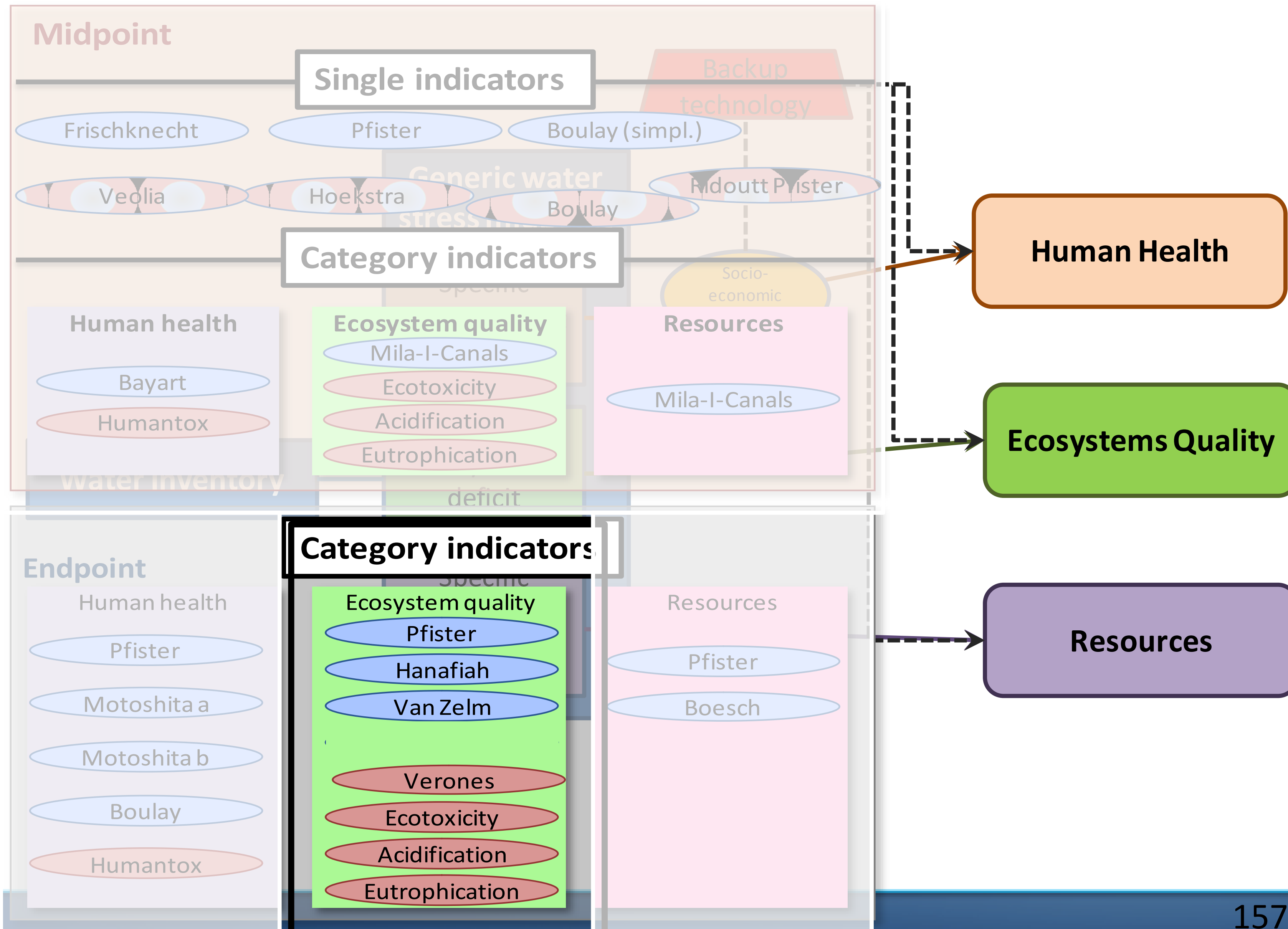
These methods are addressing the SAME impact pathways, hence they are redundant and a consensual method is needed



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



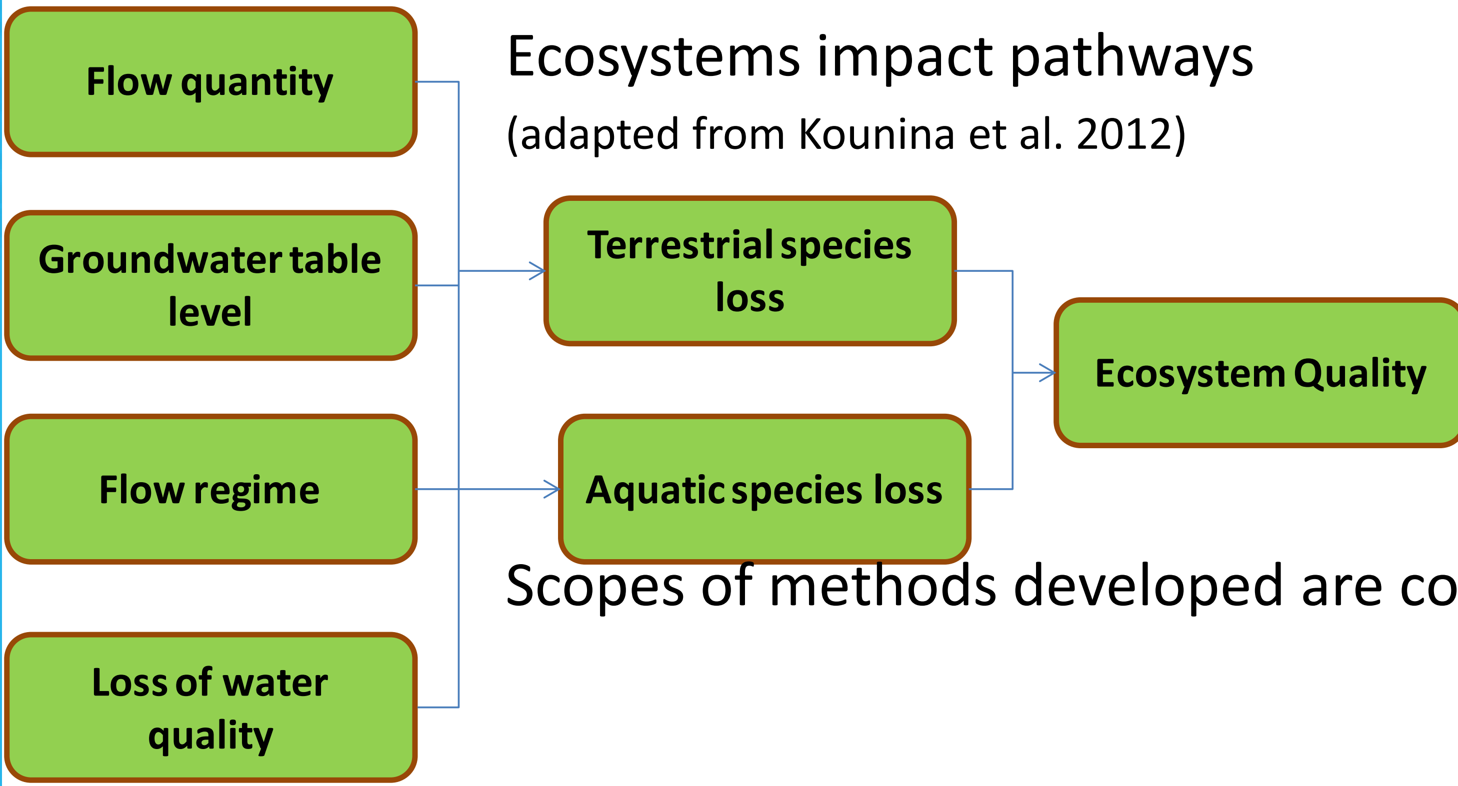
Ecosystem quality
- Pfister
- Hanafiah
- Van Zelm
- Verones
- Ecotoxicity
- Acidification
- Eutrophication

WATER AVAILABILITY METHODS

WATER QUALITY METHODS

Ecosystems impact pathways

(adapted from Kounina et al. 2012)



Scopes of methods developed are complementary

Ecosystem quality

- Pfister
- Hanafiah
- Van Zelm

WATER AVAILABILITY METHODS

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)

Ecosystem quality
Pfister
Hanafiah
Van Zelm

1- Pfister et al. 2009: Impacts on ecosystem quality

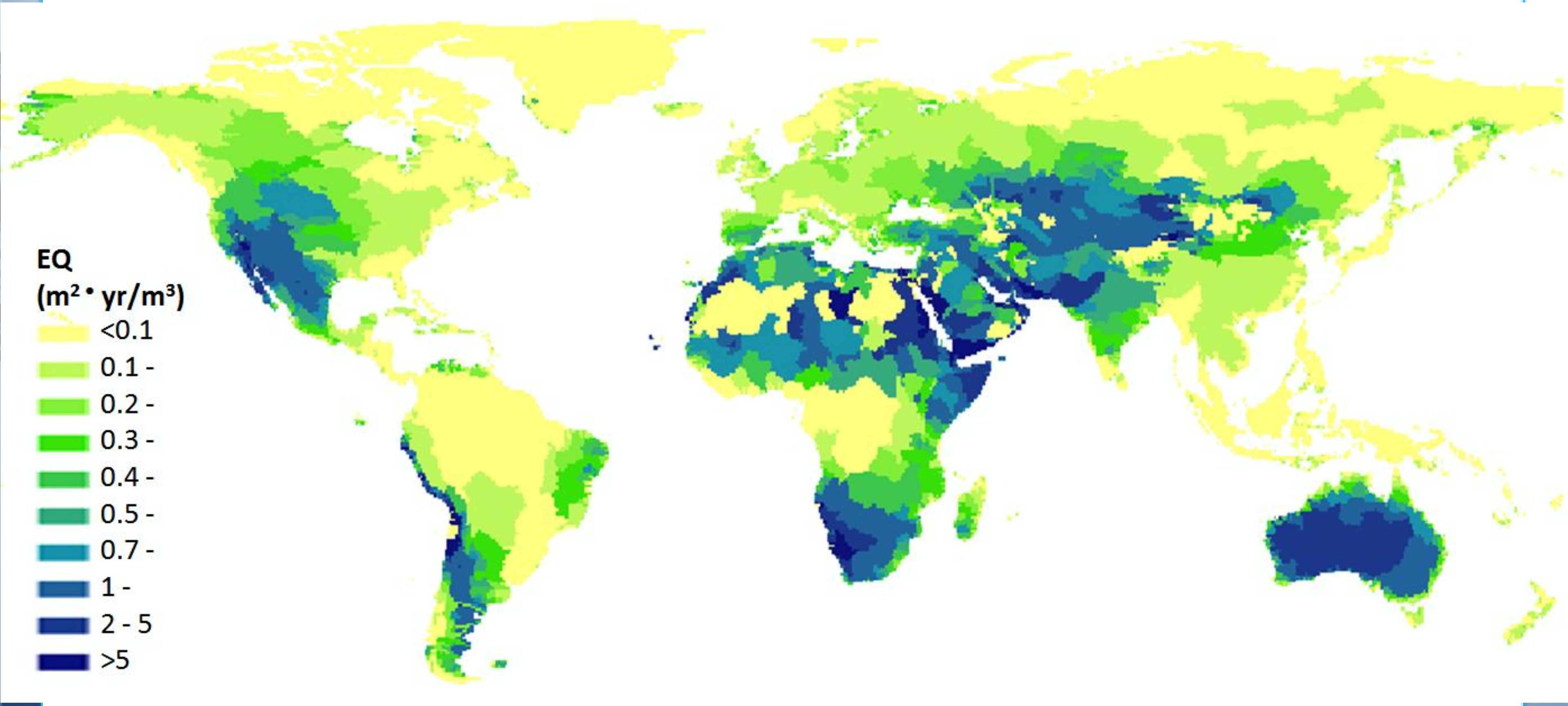
Adverse effects on ecosystem services/functions and biodiversity

$$\Delta EQ = CF_{EQ} \cdot WU_{consumptive} = \underbrace{NPP_{wat\text{-}lim}}_{PDF} \cdot \underbrace{\frac{WU_{consumptive}}{P}}_{A \cdot t}$$

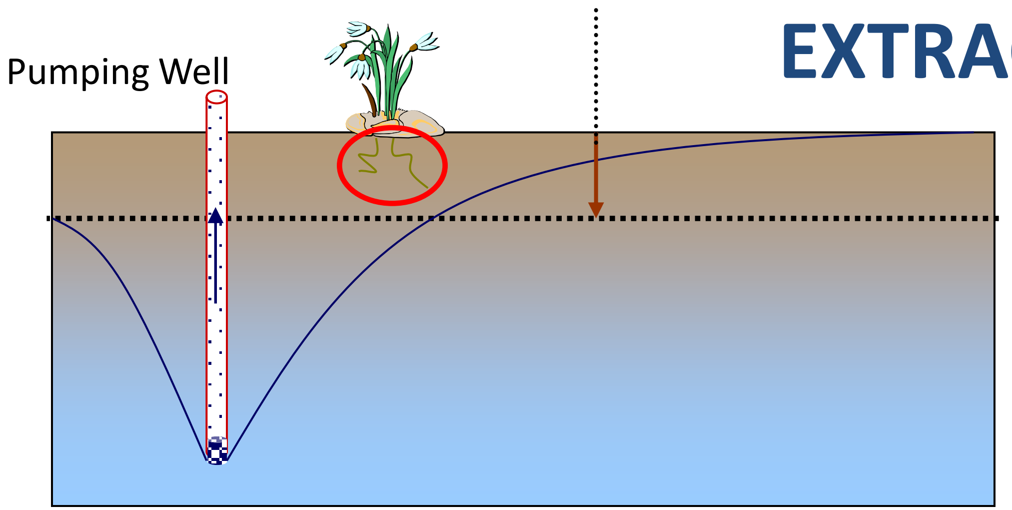
EQ: ecosystem quality damage (m2*yr)
CF(EQ): ecosystem damage factor/potential (m2*yr/m3)
WU(consumptive): consumptive water use (m3)
NPP(wat-lim): fraction of net primary production limited in growth by reduced precipitation/water availability (-)
→ water shortage vulnerability of ecosystem
PDF: potentially 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

Pfister, Koehler & Hellweg (2009), ES&T 43(11): 4098–4104

1- Pfister et al: Impacts on ecosystem Quality



2- Van Zelm et al: Groundwater Extraction



→ Potentially Not Occurring Fraction of Plant Species (PNOF)

Extraction → Lowering water level → Damage to environment

Fate $A_i * \Delta AG_i / \Delta Q_i$

Groundwater model based on MODFLOW

Effect $dPNOF_i/dAG_i$

Multiple regression curves (MOVE model)

AG = Average Groundwater level (m)

Q = Extraction rate (m^3/yr)

D = Damage (-)

- Data available for the Netherlands
- 625 terrestrial plant species; 141 on red list
- Endpoint level

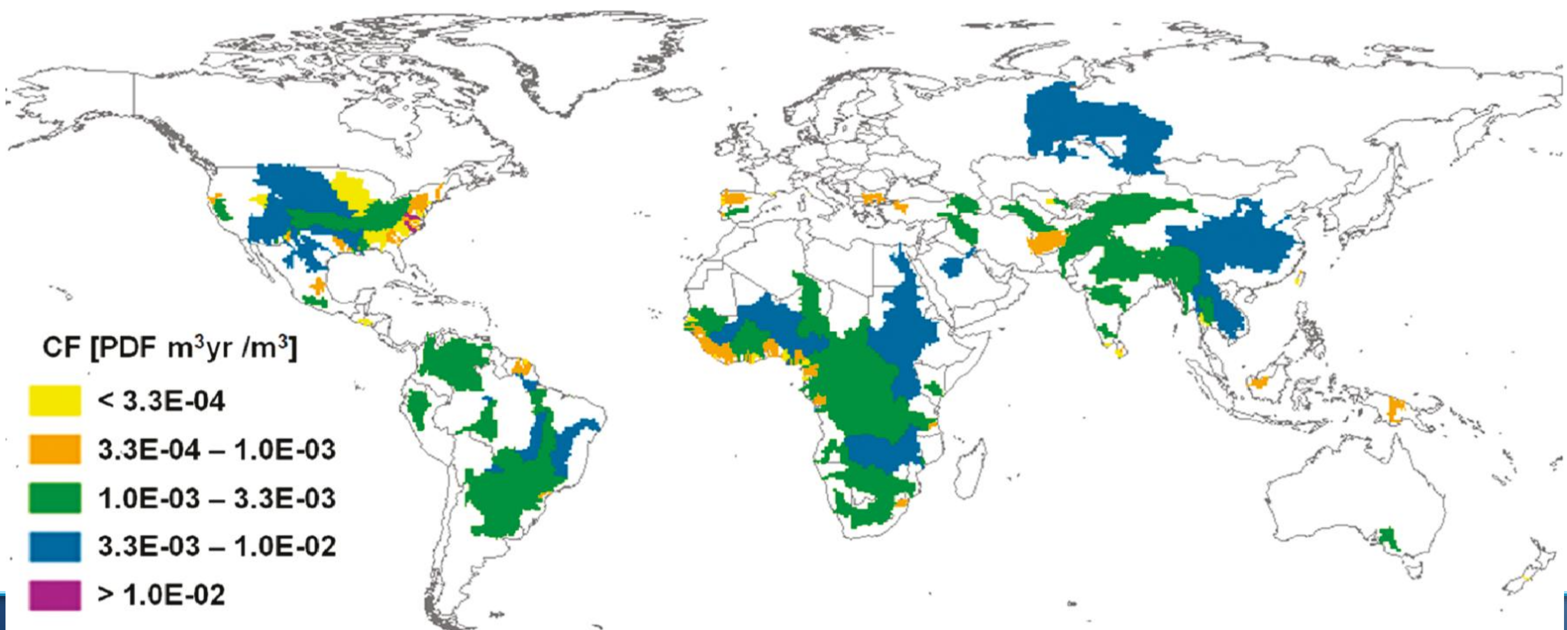
Ecosystem quality
Pfister
Hanafiah
Van Zelm

3- HANAFIAH ET AL. 2011

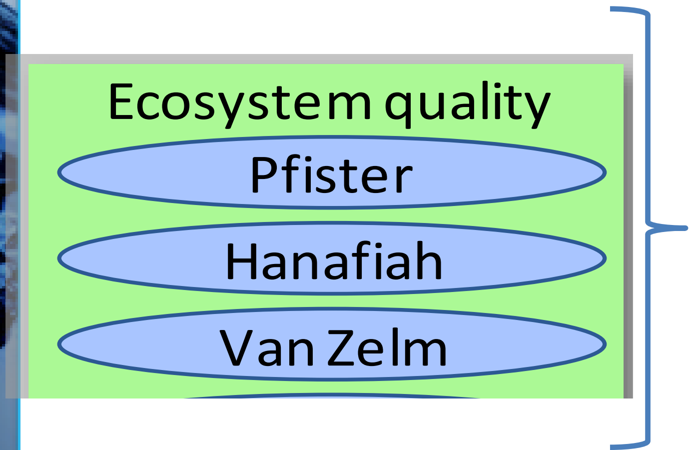
- Reduced fish species as a function of reduced river flow (Q)

W = water consumption
PDF = potentially disappeared fraction of species
V = river volume

$$CF_{wc,i} = FF_i \cdot EF_i = \underbrace{\frac{dQ_{mouth,i}}{dW_i}}_{fate} \cdot \underbrace{\left(\frac{dPDF_i}{dQ_{mouth,i}} \cdot V_i \right)}_{effect}$$



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

Verones
Ecotoxicity
Acidification
Eutrophication

Heat emissions (Verones et al. 2010)

Aim: model impacts on aquatic biodiversity of cooling water discharges to a river

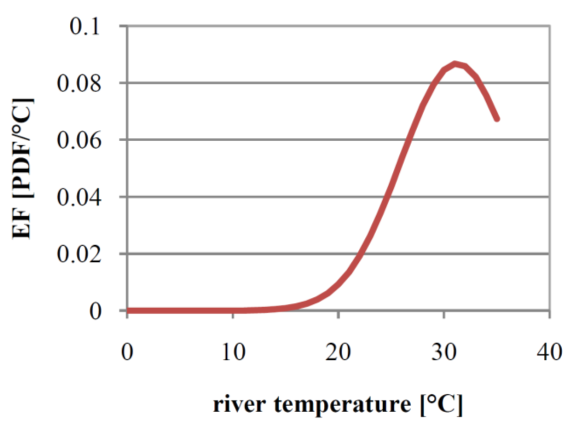
River water for cooling, ambient temperature

NPP

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

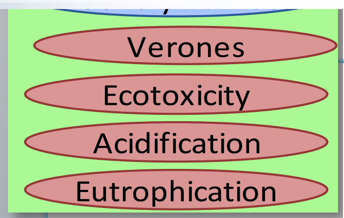
Response function for temperature induced mortality

Effect

166

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 m^2 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

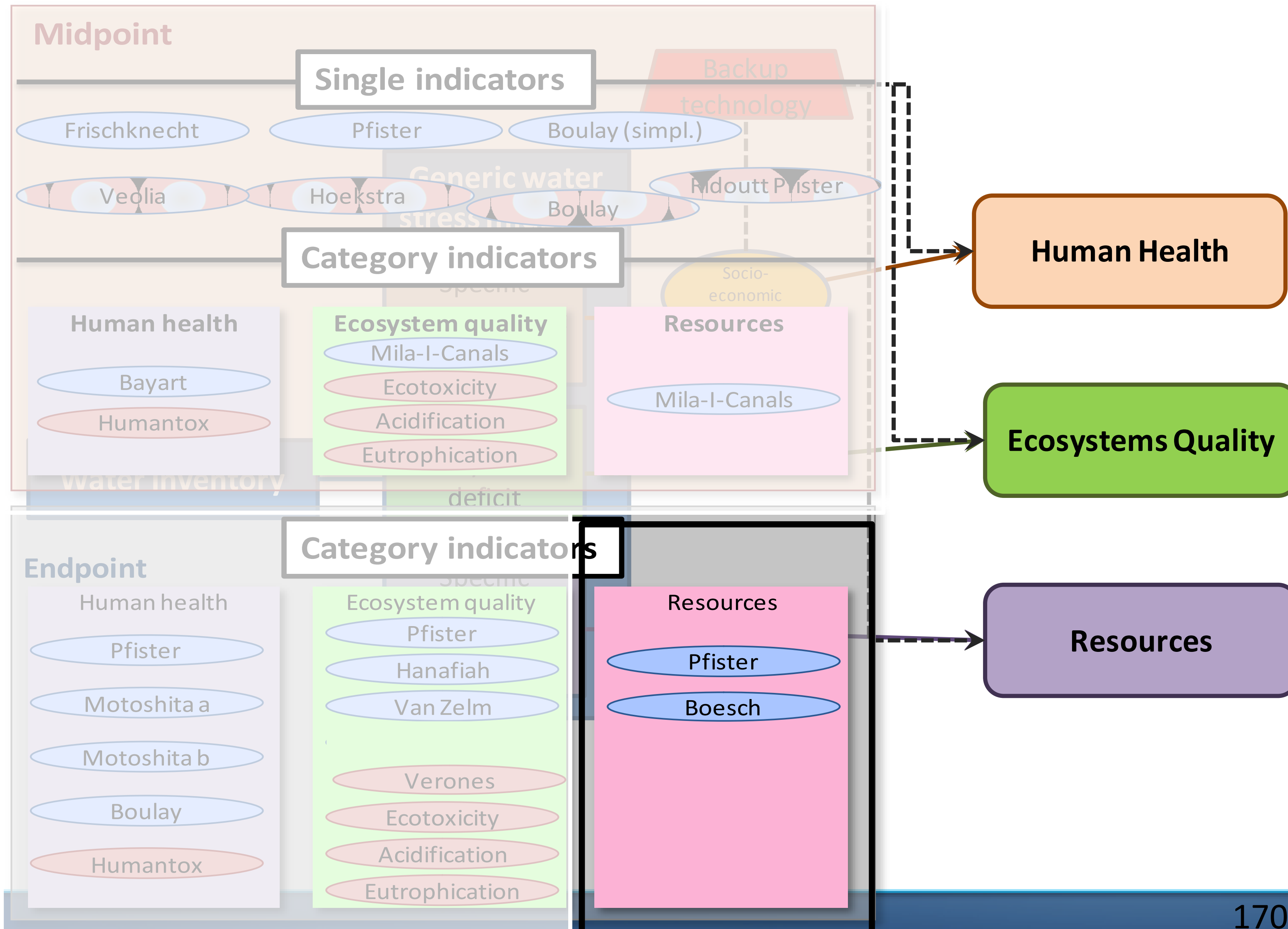
CML 2001 PLUS MIDPOINT-ENDPOINT CONVERSION (NOT RECOMMENDED)

- **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 devlopments 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 m^3yr).
- **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).

WATER IMPACTS ENDPOINT MODELING



RESOURCES

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

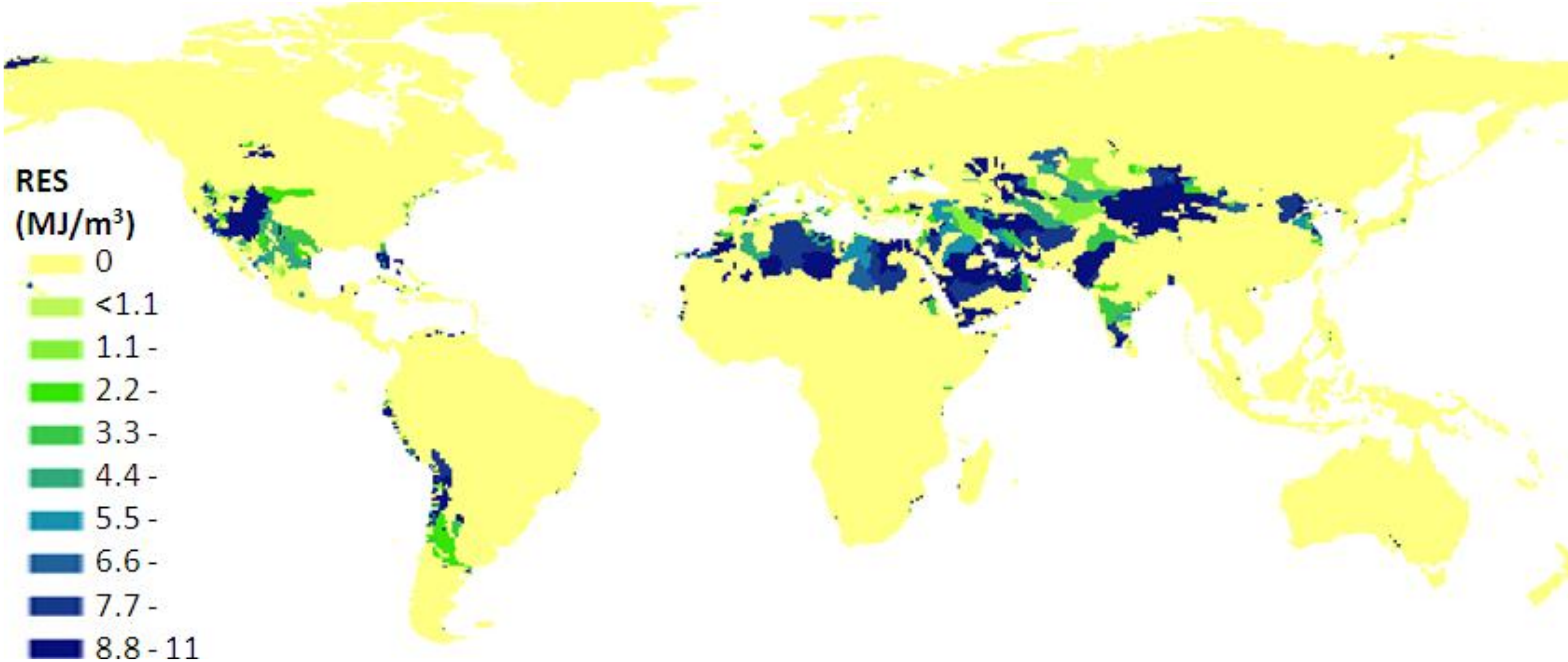
$$F_{depletion,i} = \begin{cases} \frac{WTA\ -\ 1}{WTA} & for\ \ WTA > 1 \\ 0 & for\ \ WTA \leq 1 \end{cases}$$

- Desalination as backup technology

$$\Delta RD\ = F_{depletion} \cdot MJ_{surplus} \cdot WU_{consumptive}$$

Pfister, Koehler & Hellweg (2009), ES&T 43(11): 4098–4104

Impacts on resources



Pfister, Koehler & Hellweg (2009), ES&T 43(11): 4098–4104

EXERGY BASED RESOURCE INDICATOR

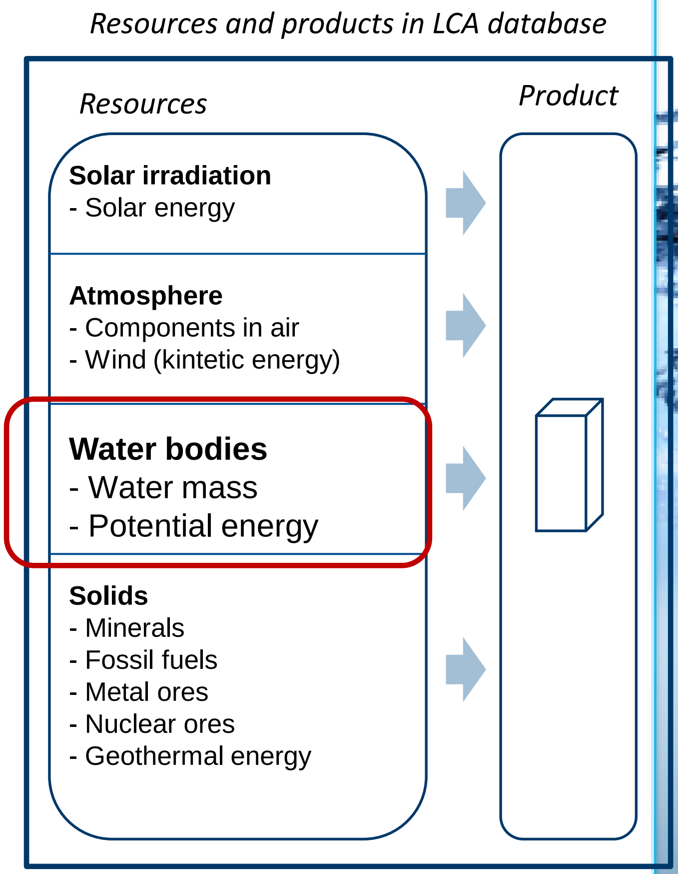
Exergy

- 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

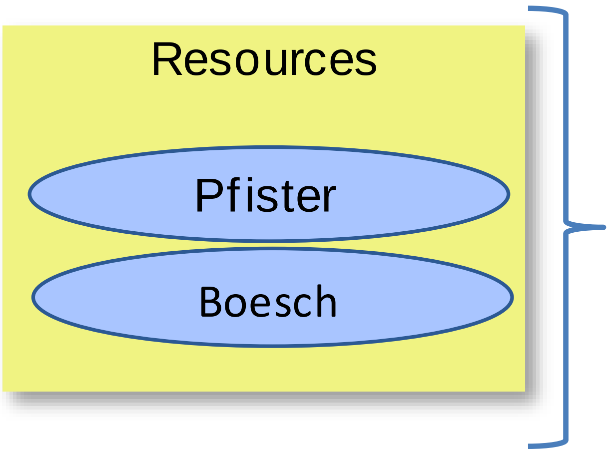
- Consistent framework
- No value choices
- No assumptions on future availability needed (recovery, substitution)
- All resources can be assessed

Potential energy of water and water mass is assessed



Boesch et al. (2007)

Important note

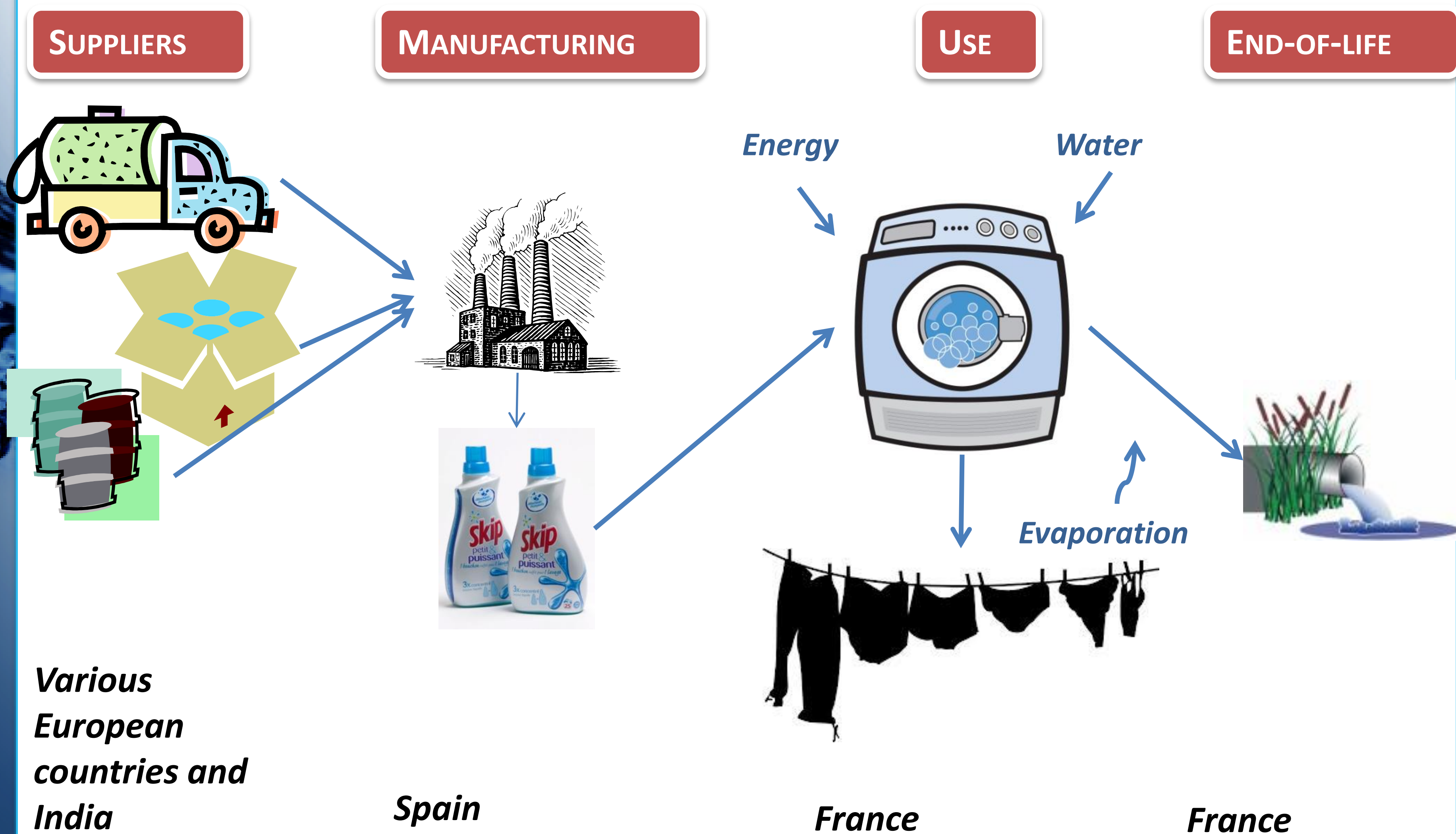


There is no consensus yet on the use of these methods in this impact category, more research is needed

EXAMPLES

Water Footprint at the endpoint

WATER FOOTPRINT OF A LOAD OF LAUNDRY



Boulay, A.-M., Bayart, J.-B., Bulle, C., Franceschini, H., Motoshita, M., Muñoz, I., Pfister, S., et al. (2013). Water impact assessment methods analysis (Part B): Applicability for water footprinting and decision making with a laundry case study. *International Journal of Life Cycle Assessment, Submitted.*

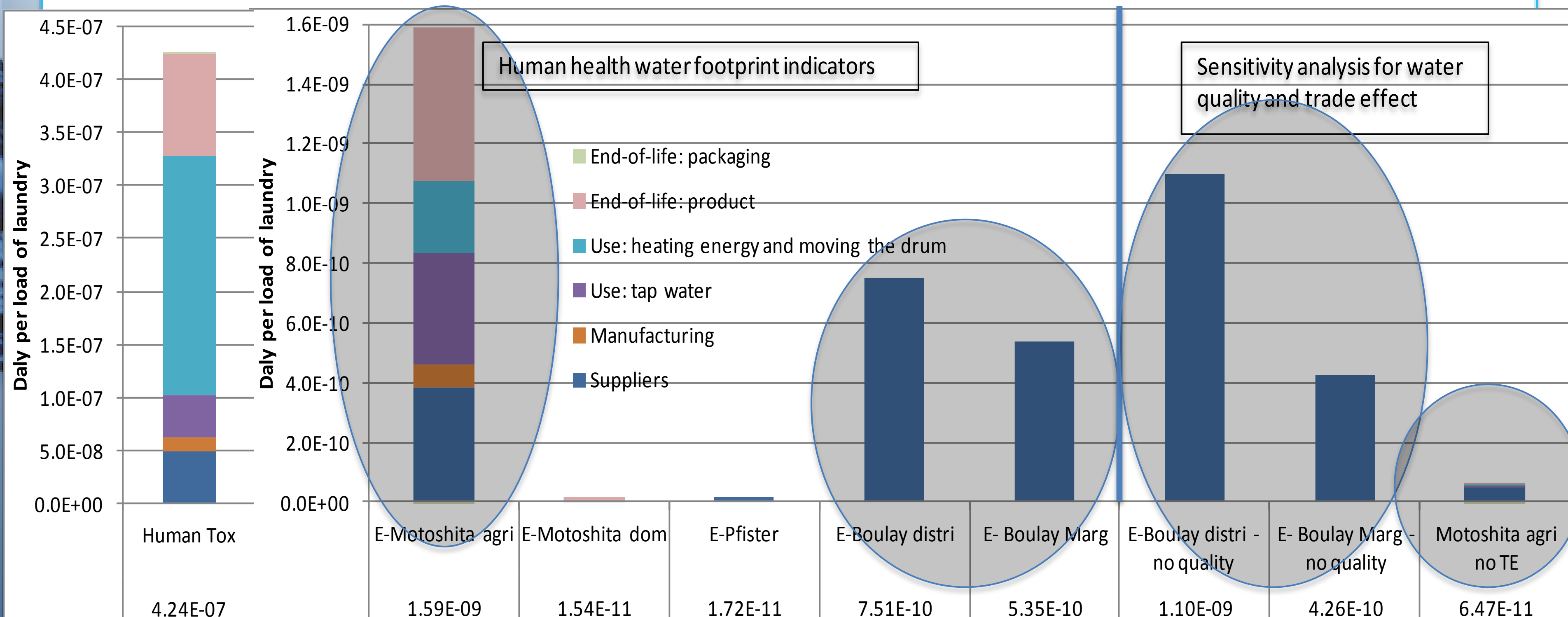
METHODOLOGY OVERVIEW - ENDPOINT

Water Footprint profile at endpoint: Ecosystems and human health impacts

	Indicator	Reference
	Water Availability	
6	Human Health (DALY)	Pfister et al.
6	→ ONLY ONE METHOD NEEDED	Motoshita et al.
6		Boulay et al
6		Boulay et al.
7	Ecosystems Quality (PDF*m2*yr)	Pfister et al.
8		Hannafiah et al.
9		Van Zelm et al.
	Water Degradation	
10	Ecosystems Quality (PDF*m2*yr)	Thermal pollution, Verones et al.
11		Eutrophication, Goedkoop et al.
12		Acidification, Impact 2002+
13		Ecotoxicity, Usetox
14	HH: Human Health (DALY)	Human Toxicity, Usetox

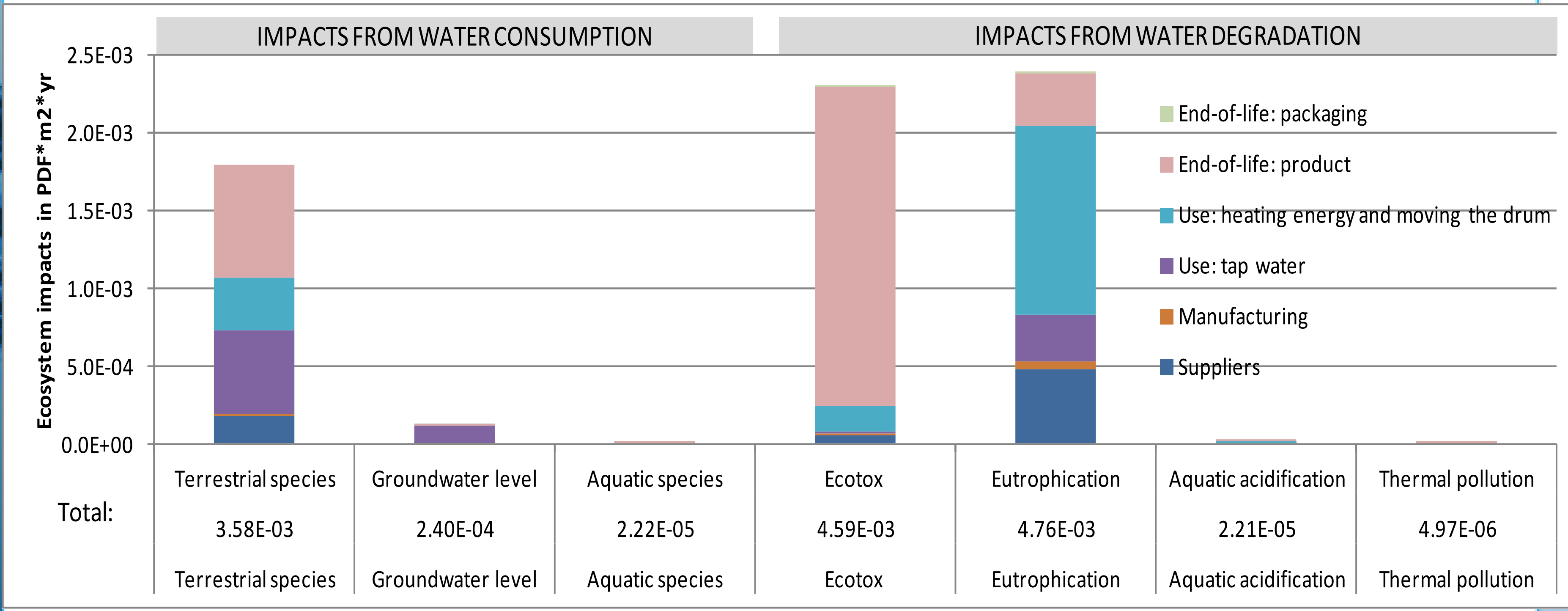
Boulay, A.-M., Bayart, J.-B., Bulle, C., Franceschini, H., Motoshita, M., Muñoz, I., Pfister, S., et al. (2013). Water impact assessment methods analysis (Part B): Applicability for water footprinting and decision making with a laundry case study. *International Journal of Life Cycle Assessment*, *Submitted*.

Endpoint WF profile Human health



Boulay, A.-M., Bayart, J.-B., Bulle, C., Franceschini, H., Motoshita, M., Muñoz, I., Pfister, S., et al. (2013). Water impact assessment methods analysis (Part B): Applicability for water footprinting and decision making with a laundry case study. *International Journal of Life Cycle Assessment*, *Submitted*.

ENDPOINT WF PROFILE ECOSYSTEMS

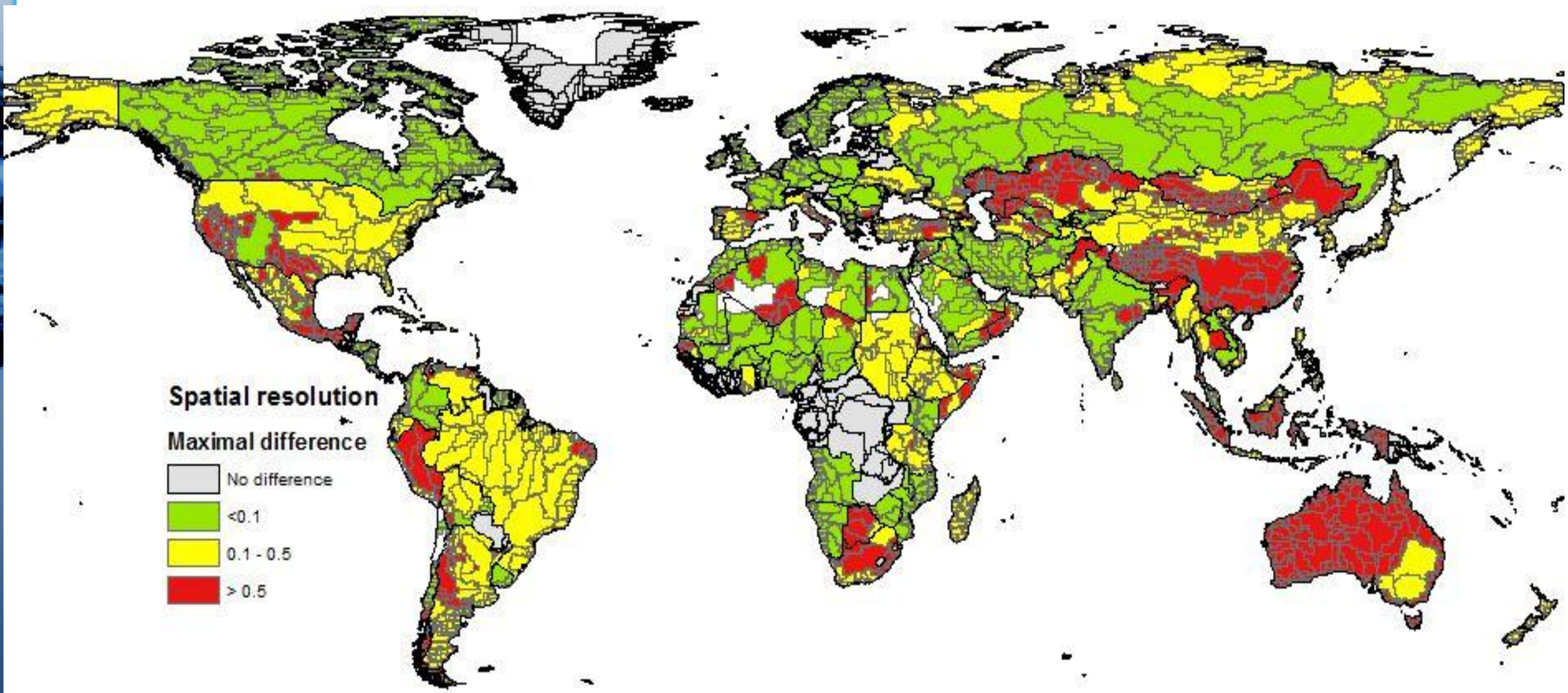


Boulay, A.-M., Bayart, J.-B., Bulle, C., Franceschini, H., Motoshita, M., Muñoz, I., Pfister, S., et al. (2013). Water impact assessment methods analysis (Part B): Applicability for water footprinting and decision making with a laundry case study. *International Journal of Life Cycle Assessment*, *Submitted*.

UNCERTAINTY AND VARIATION

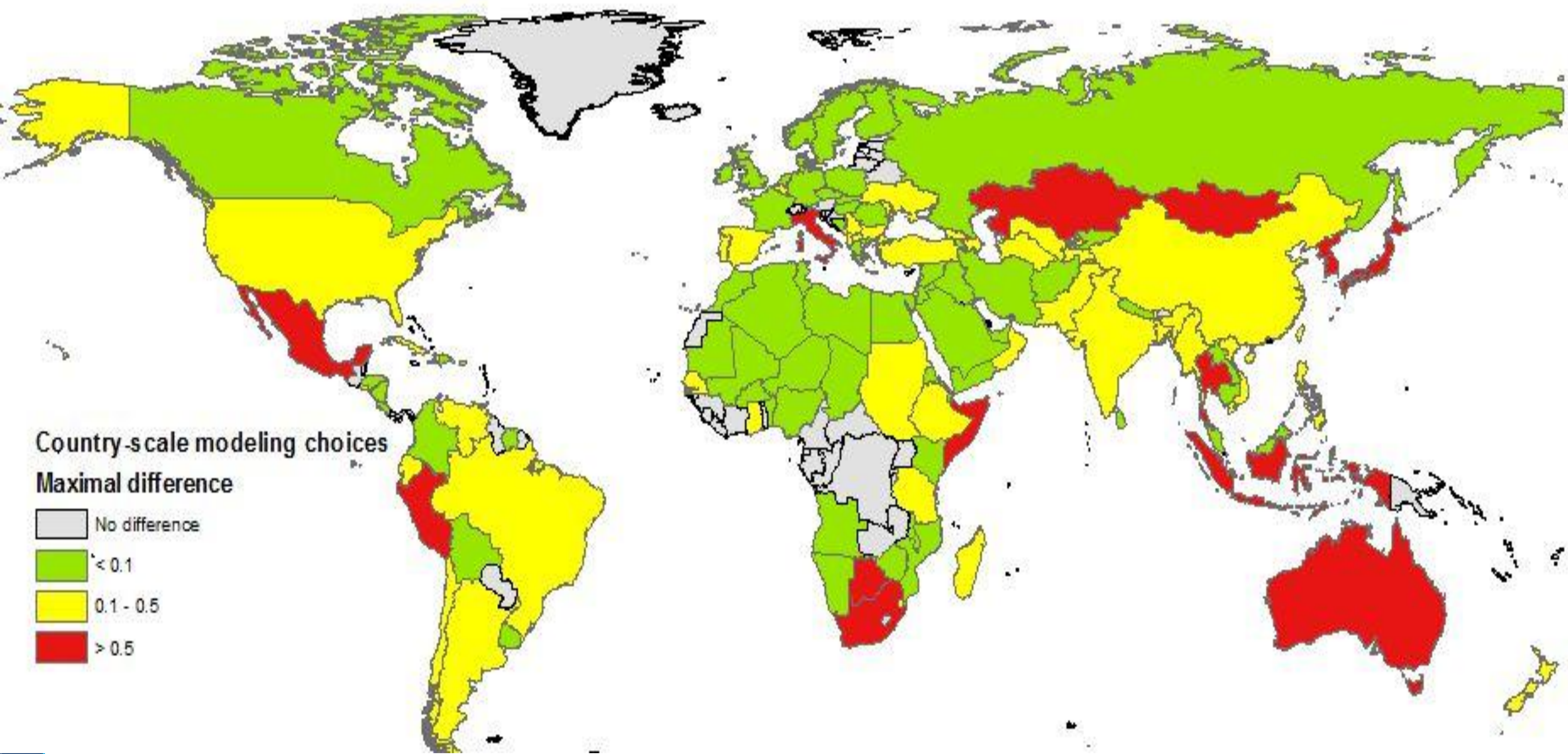
TIME AND GEOGRAPHICAL RESOLUTION

Maximal difference between sub-watershed and country scarcity



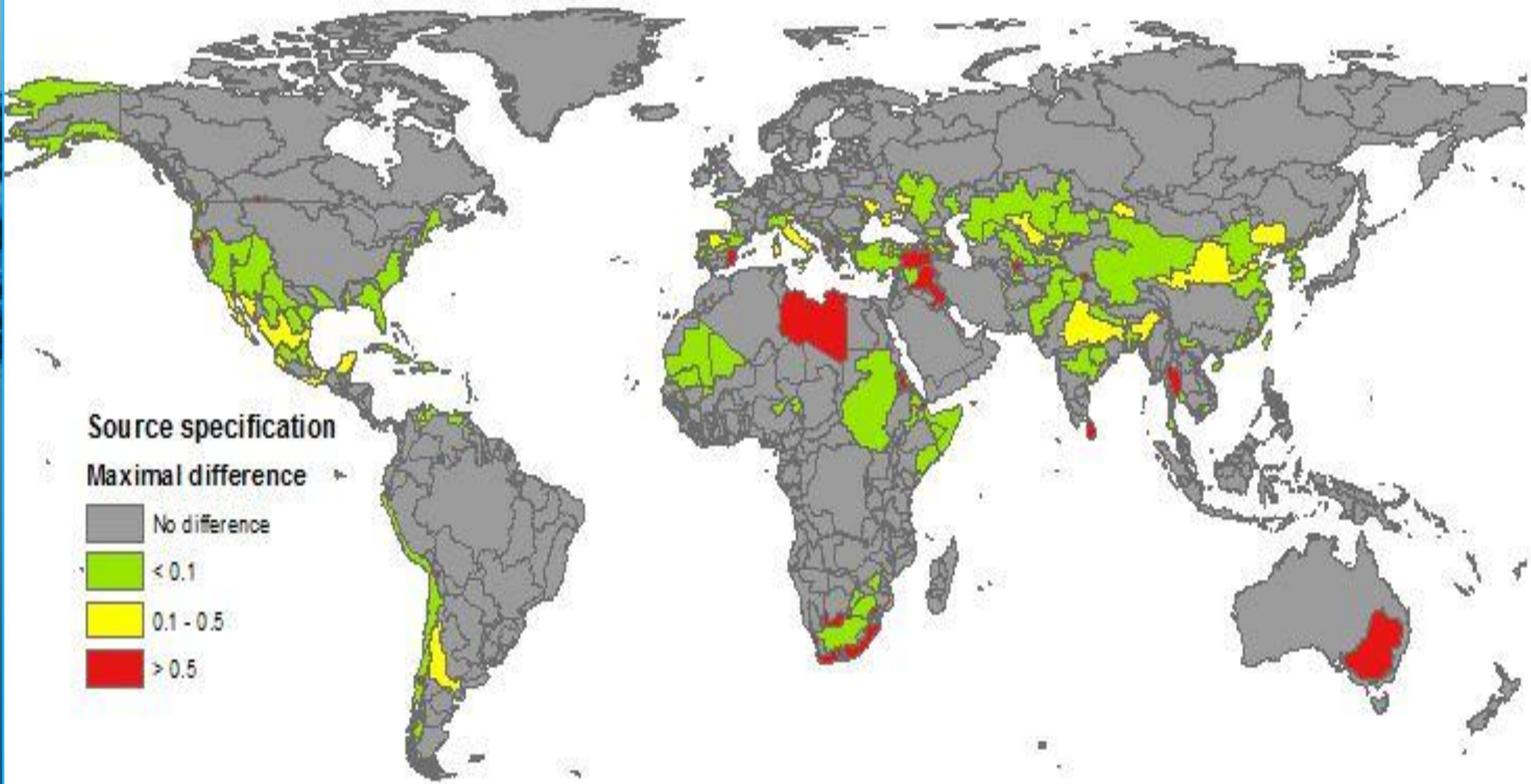
Source: Boulay, A.-M., Motoshita, M., Pfister, S., Bulle, C., Muñoz, I., Franceschini, H., & Margni, M. (2013). Water use impact assessment methods (Part A): Methodological and quantitative comparison of scarcity and human health impacts models. *International Journal of Life Cycle Assessment*, *Submitted*.

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



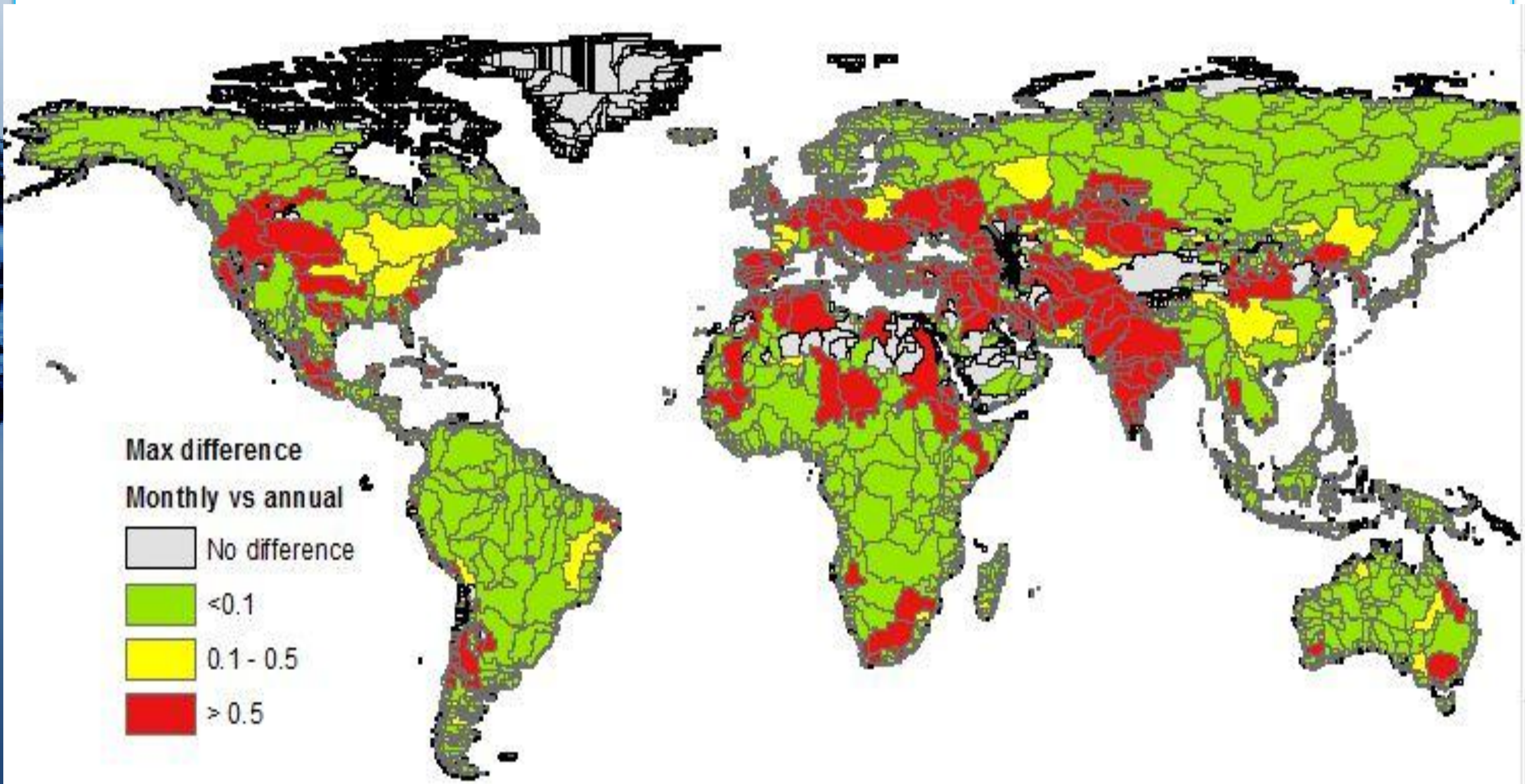
Source: Boulay, A.-M., Motoshita, M., Pfister, S., Bulle, C., Muñoz, I., Franceschini, H., & Margni, M. (2013). Water use impact assessment methods (Part A): Methodological and quantitative comparison of scarcity and human health impacts models. *International Journal of Life Cycle Assessment*, *Submitted*.

Maximal difference between source-specified water scarcity and unspecified



Source: Boulay, A.-M., Motoshita, M., Pfister, S., Bulle, C., Muñoz, I., Franceschini, H., & Margni, M. (2013). Water use impact assessment methods (Part A): Methodological and quantitative comparison of scarcity and human health impacts models. *International Journal of Life Cycle Assessment*, *Submitted*.

MAXIMAL DIFFERENCE BETWEEN THE ANNUAL SCARCITY AND THE WETTEST/DRIEST MONTH



Source: Boulay, A.-M., Motoshita, M., Pfister, S., Bulle, C., Muñoz, I., Franceschini, H., & Margni, M. (2013). Water use impact assessment methods (Part A): Methodological and quantitative comparison of scarcity and human health impacts models. *International Journal of Life Cycle Assessment*, *Submitted*.

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

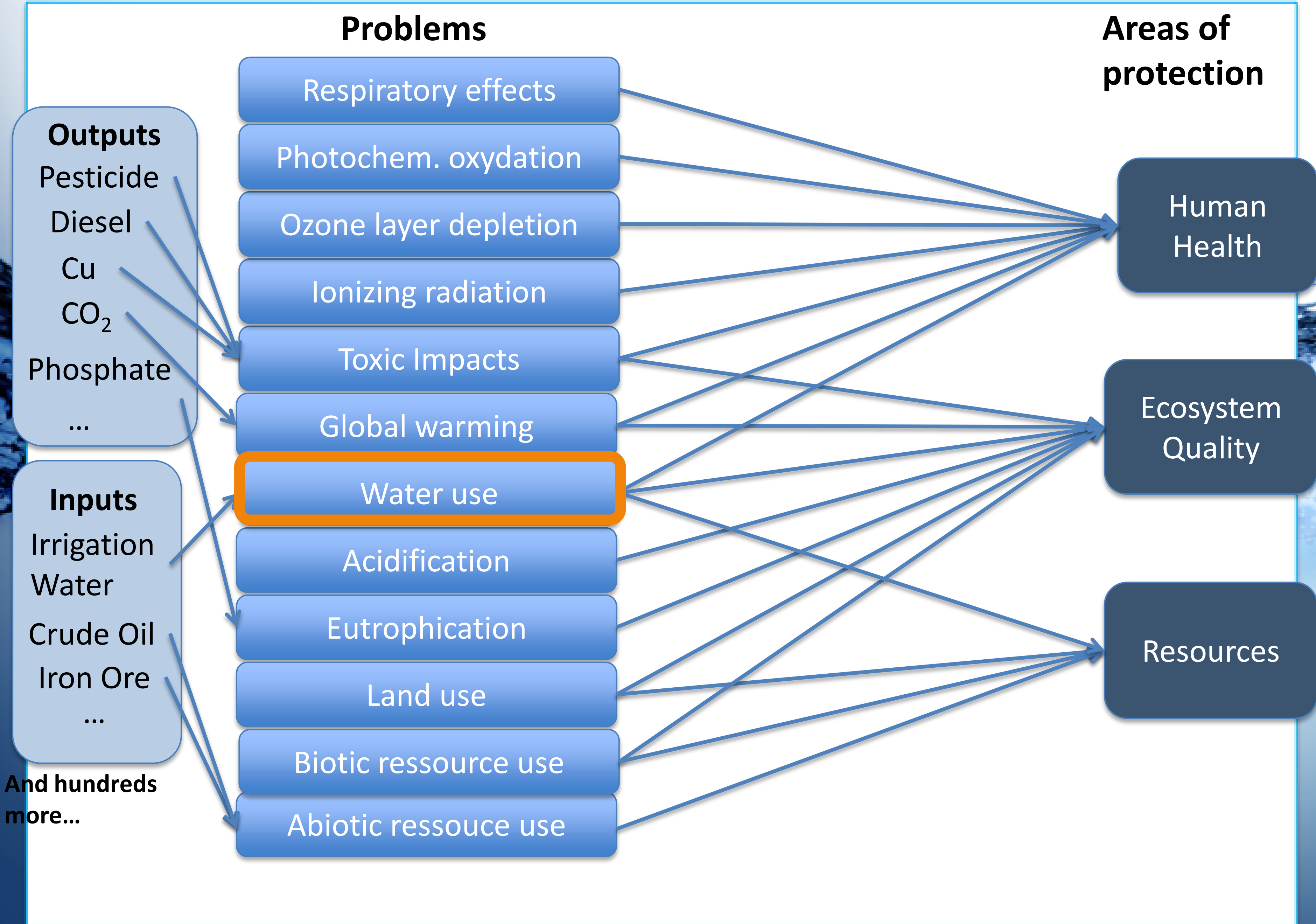
- LCA based water footprint is mainly useful for **understanding the system** and options for most effective improvement of the total system under study
- It **quantifies** and **localizes** potential environmental issues in the **whole system over the life cycle**
- It is difficult to use it for absolute comparison as done for **EPD** (environemntal produt 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

1000 kg of aluminum

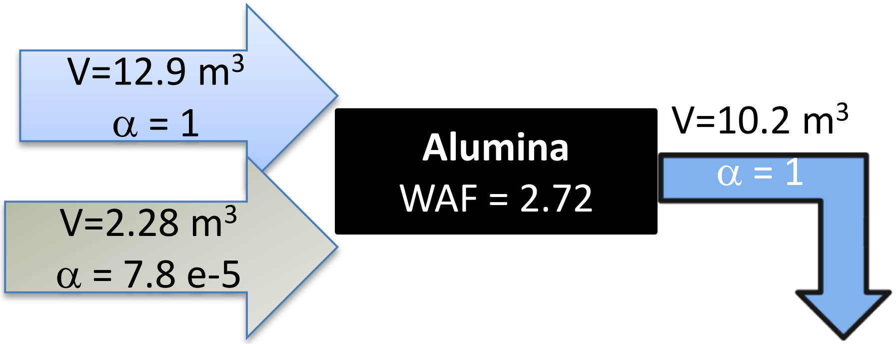
- *Bauxite mining*
- *Alumina production*
- *Anode production*
- *Electrolysis*
- *Ingot casting*


Problems
Areas of protection
Outputs
Pesticide
Diesel
Cu
CO2
Phosphate
…
Inputs
Irrigation Water
Crude Oil
Iron Ore
…
And hundreds more…
Respiratory effects
Photochem. oxydation
Ozone layer depletion
Ionizing radiation
Toxic Impacts
Global warming
Water use
Acidification
Eutrophication
Land use
Biotic ressource use
Abiotic ressouce use
Human Health
Ecosystem Quality
Resources

CALCULATION FOR EACH PROCESS STEP AND RESULTING WATER AVAILABILITY FOOTPRINT (WAF)

α = stress CF

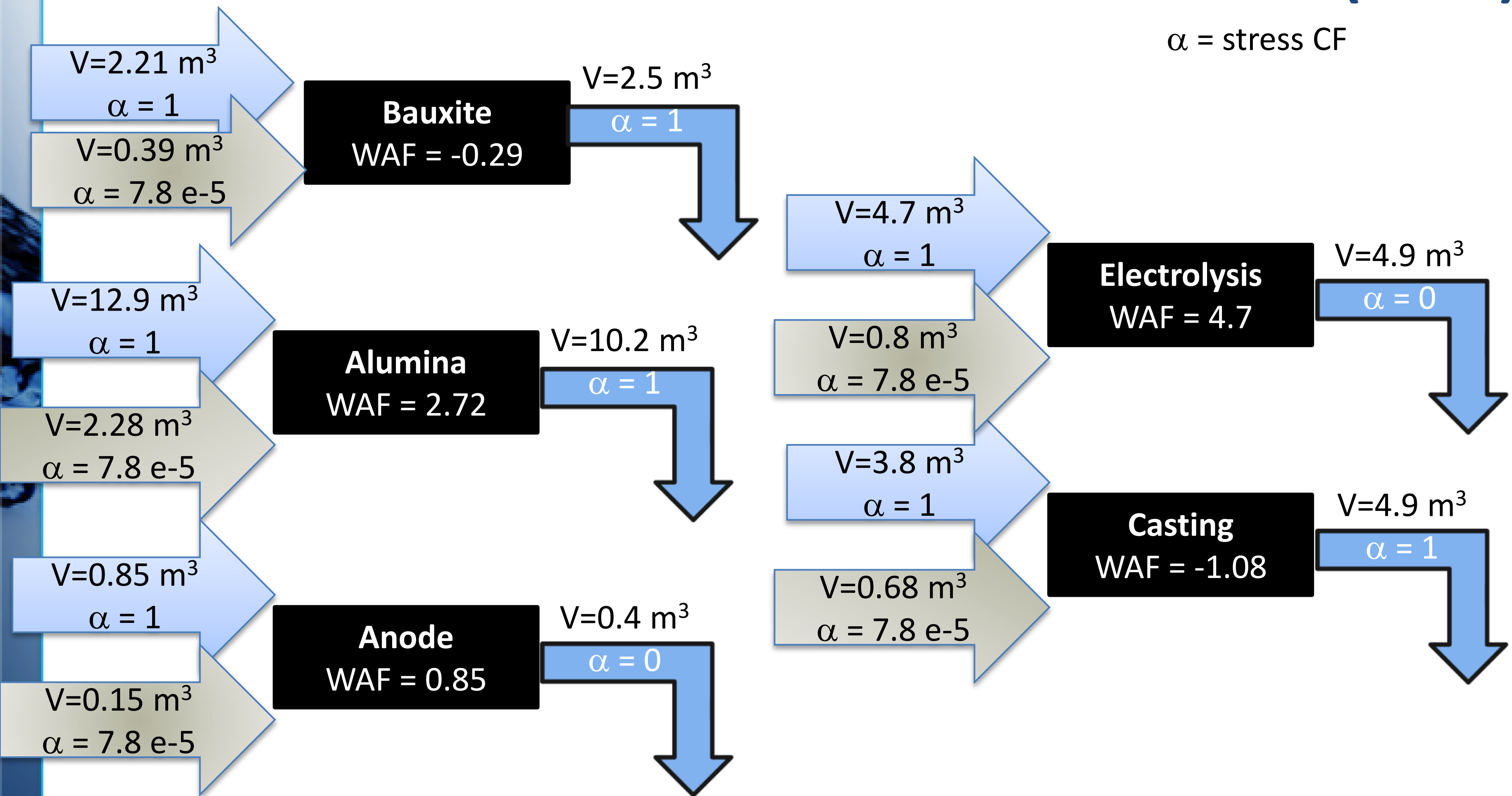
WAF = (12.9 x 1) + (2.28 x 7.8e-5) – (10.2 x 1)



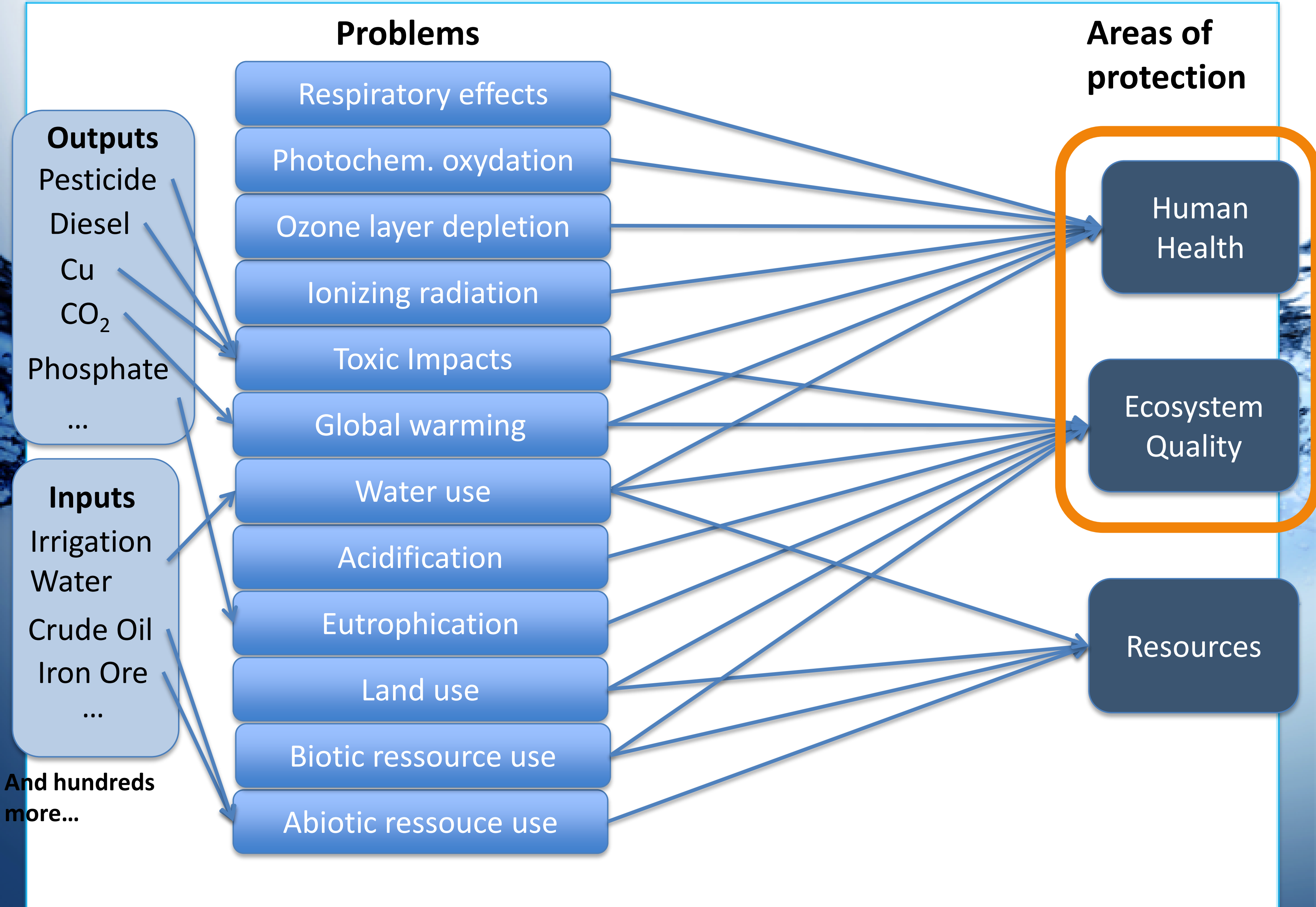
WAF = 2.72

Calculation for each process step and resulting water availability footprint (WAF)

α = stress CF



WAF = 2.72 - 0.29 + 0.85 + 4.7 – 1.08 = 6.91 m³ eq.


Problems
Areas of protection
Outputs
Pesticide
Diesel
Cu
CO_2
Phosphate
…
Inputs
Irrigation Water
Crude Oil
Iron Ore
…
And hundreds more…
Respiratory effects
Photochem. oxydation
Ozone layer depletion
Ionizing radiation
Toxic Impacts
Global warming
Water use
Acidification
Eutrophication
Land use
Biotic ressource use
Abiotic ressouce use
Human Health
Ecosystem Quality
Resources

Water Footprint Profile Calculations using Impact World + (all methodologies below included)

Ecosystems WF

+

Human Health WF

Impacts from resource availability

(e.g. Pfister et al. + Hannafiah et al.+ Van Zelm et al.)

+

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

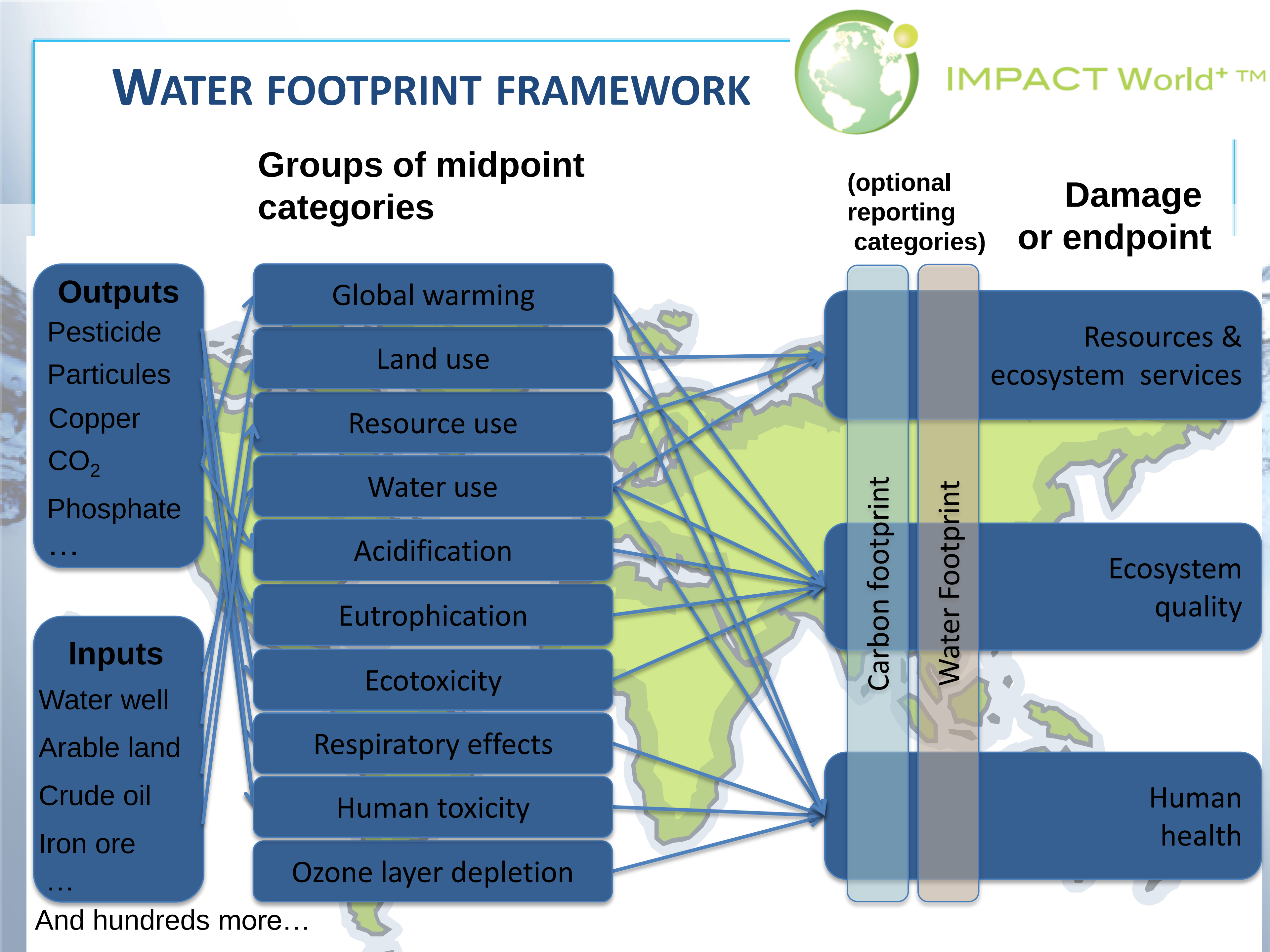
(e.g. Boulay et al, 2011)

+

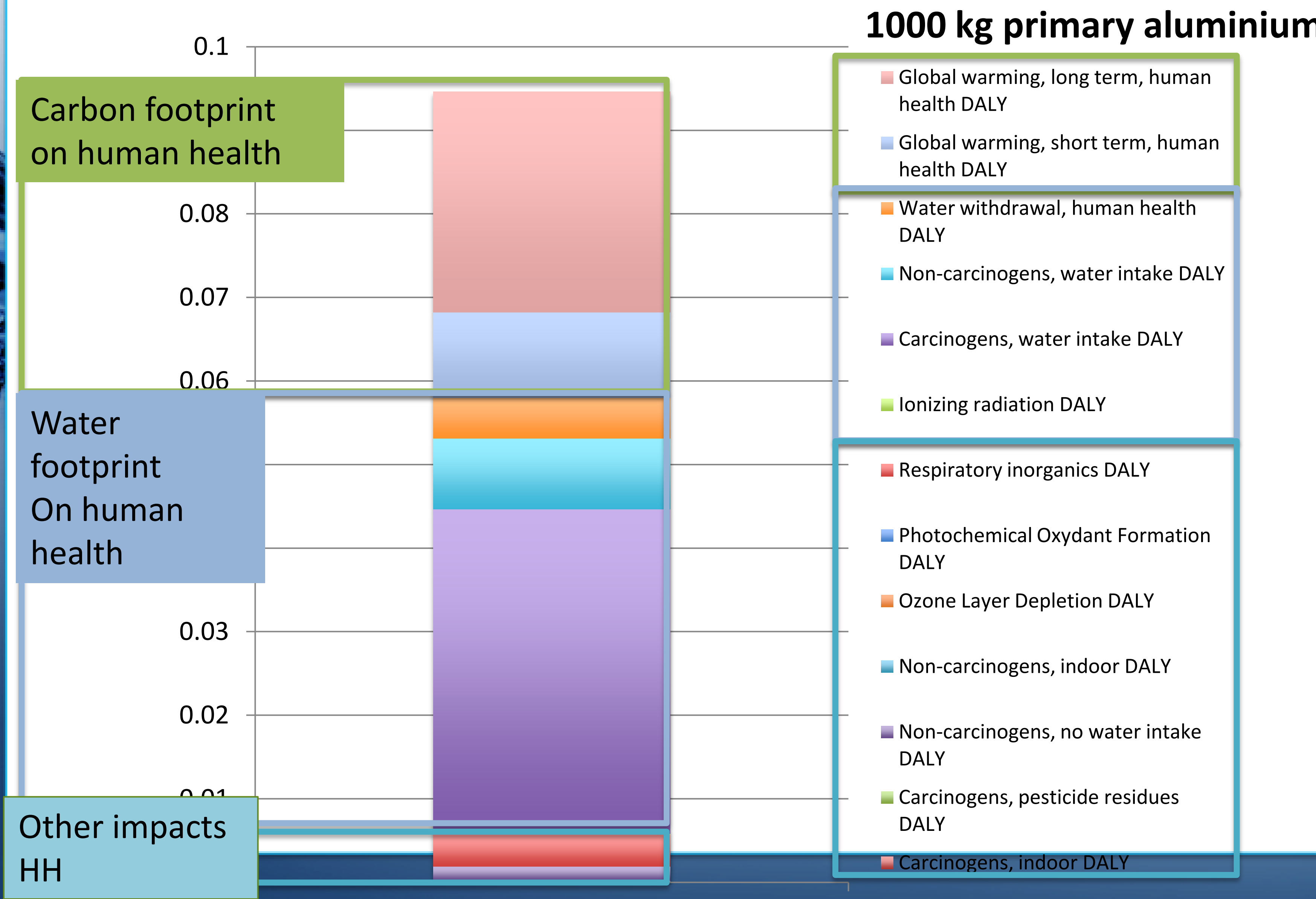
Impacts from pollution emissions:

Ionising radiation and human toxicity (only through aquatic routes of exposure)

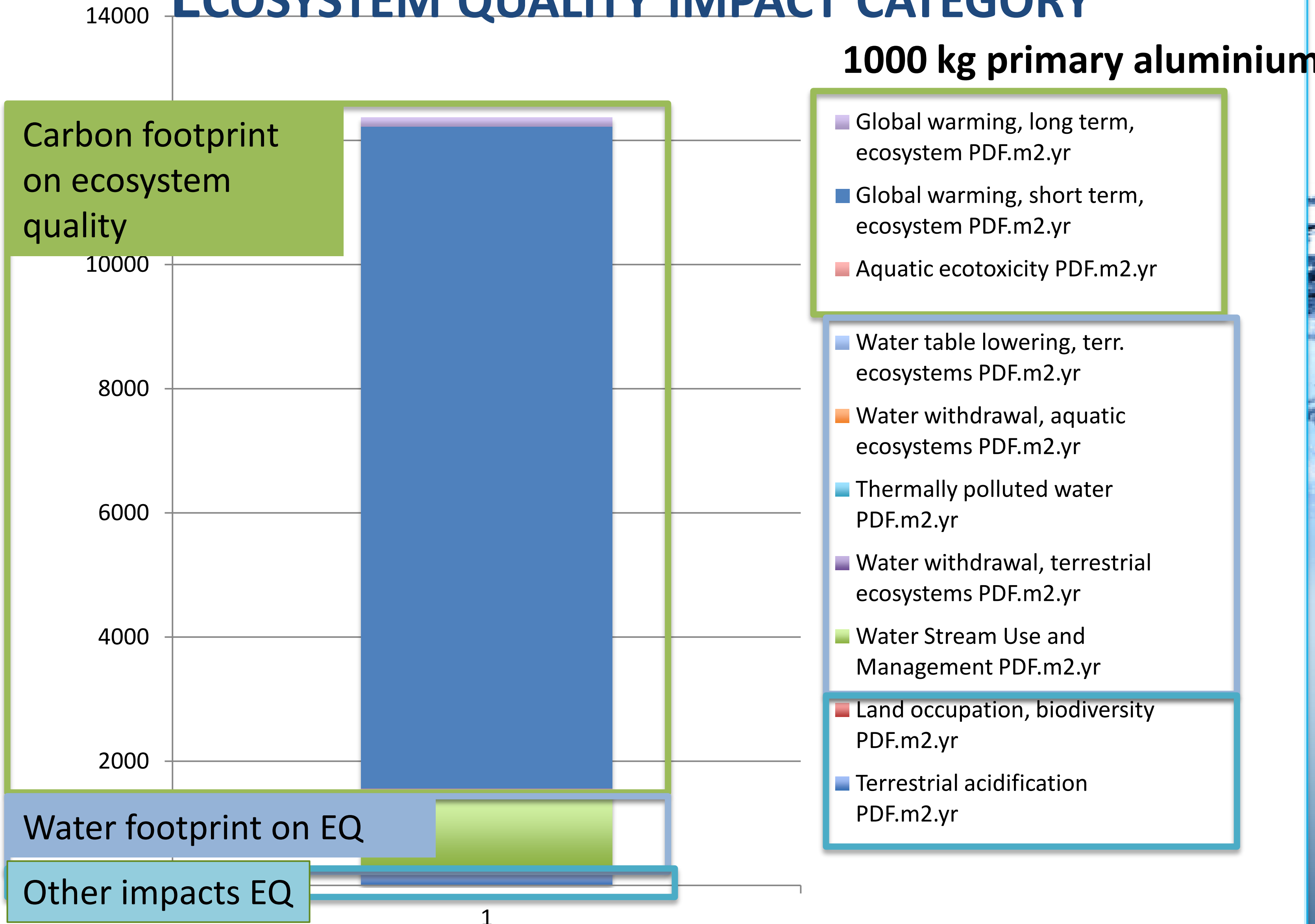
WATER FOOTPRINT FRAMEWORK



Water Footprint as part of an LCA: Human health impact category



Water Footprint as part of an LCA: Ecosystem quality impact category



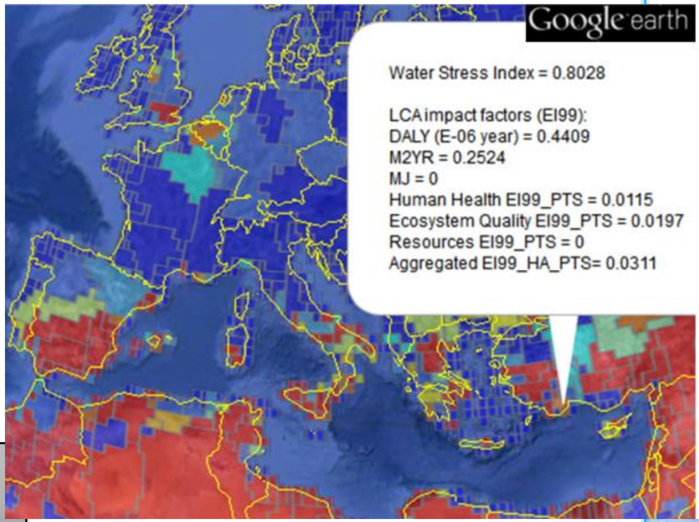
Impact assessment methods availability and references

PFISTER ET AL. 2009

- 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):

http://www.ifu.ethz.ch/ESD/downloads/reports/Monthly_WSI_LCA_FOOD.pdf

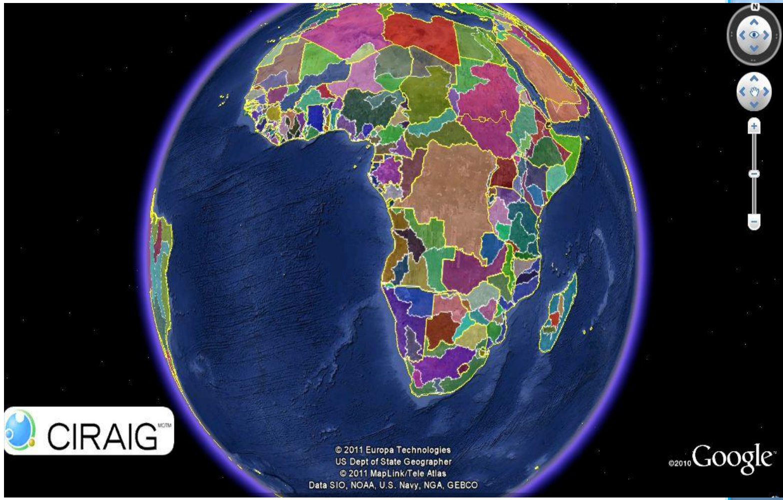
BOULAY ET AL. 2011

- Impact Assessment method including quality aspects

  Boulay A-M, Bulle C, Bayart J-B, Deschênes L, Margni M (2011b) Regional characterization of freshwater use in LCA: modeling direct impacts on human health. Environmental Science and Technology

Results and more data/tools

IMPACT World WATER TOOL



www.ciraig.org/wateruseimpacts

WFN Blue water scarcity

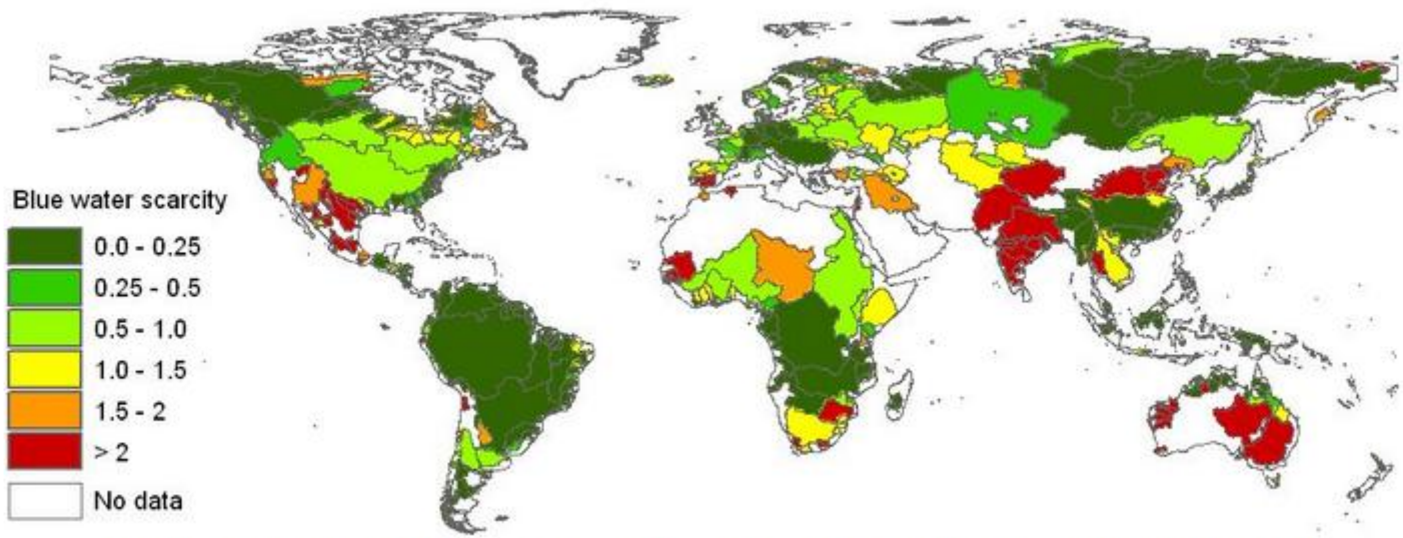
Spreadsheet and shapefile available online (for 405 watersheds);

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



Annual average monthly blue water scarcity in the world's major river basins (1996-2005)

Figure: Hoekstra et al. (2012)

OUTLOOK

- Quantis Water Database
- Ecoinvent 3
- IMPACT WORLD +
- SimaPro 8

QUESTIONS

REFERENCES

References I

Alcamo, J., Henrichs, T., Rösch, T., (2000). World water in 2025: Global modeling and scenario analysis. In: Rijsberman, F. (Ed.), World Water Scenarios. Earthscan Publications, London, pp. 243-281.

Bayart JB, Bulle C, Deschênes L, Margni M, Pfister S, Vince F, Koehler A (2010) A framework for assessing off-stream freshwater use in LCA. Int J Life Cycle Ass 15:439-453

Bayart J, Grimaud J, E A (2011) The Water Impact Index: a simplified single-indicator approach for water footprinting. The International Journal of Life Cycle Assessment (submitted)

Berger M, Finkbeiner M (2010) Water footprinting: How to assess water use in life cycle assessment? Sustainability 2:919-944

Berger M., J. Warsen, S. Krinke, V. Bach, M. Finkbeiner (2012): Water footprint of European cars: potential impacts of water consumption along automobile life cycles. Environmental Science and Technology (in press), DOI: 10.1021/es2040043

Boesch, M. E.; Hellweg, S.; Huijbregts, M. A. J.; Frischknecht, R. (2007) Applying cumulative exergy demand (CExD) indicators to the ecoinvent database. Int J Life Cycle Ass 12, 181-190

Boulay A-M, Bouchard C, Bulle C, Deschênes L, Margni M (2011a) Categorizing water for LCA inventory. The International Journal of Life Cycle Assessment 16 (7):639-651

Boulay A-M, Bulle C, Bayart J-B, Deschênes L, Margni M (2011b) Regional characterization of freshwater use in LCA: modeling direct impacts on human health. Environmental Science and Technology

Boulay, A.-M., Motoshita, M., Pfister, S., Bulle, C., Muñoz, I., Franceschini, H., & Margni, M. (2013). Water use impact assessment methods (Part A): Methodological and quantitative comparison of scarcity and human health impacts models. *International Journal of Life Cycle Assessment*, *Submitted*.

Boulay, A.-M., Bayart, J.-B., Bulle, C., Franceschini, H., Motoshita, M., Muñoz, I., Pfister, S., et al. (2013). Water impact assessment methods analysis (Part B): Applicability for water footprinting and decision making with a laundry case study. *International Journal of Life Cycle Assessment*, *Submitted*.

References II

Chapagain AK, Hoekstra AY (2004) Water footprints of nations: Volume 1: Main report. Research report series no. 16. UNESCO-IHE, Delft

CEO Water Mandate (2010) Guide to Responsible Business Engagement with Water Policy. United Nations Global Compact, Pacific Institute,November 2010, ISBN: 1-893790-30-4; http://ceowatermandate.org/files/Guide_Responsible_Business_Engagement_Water_Policy.pdf)

Ecoinvent (2007) Ecoinvent center. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland,

ESD (2012). Water inventory data. http://www.ifu.ethz.ch/ESD/downloads/WATER_DATA

Eymann, L. 2010. Bachelor thesis at ETH Zurich: Virtual Water in a Pizza (in German). Available at: http://www.ifu.ethz.ch/ESD/downloads/reports/pizzaWFP.pdf

Falkenmark M, Lundqvist J, Widstrand C (1989) Macro-scale water scarcity requires micro-scale approaches. Aspects of vulnerability in semi-arid development. Natural Resources Forum 13 (4):258-267

Falkenmark M, Rockstrom J (2004) Balancing water for humans and nature: The new approach in ecohydrology. Earthscan, London

Feng K., Chapagain A., Suh S, Pfister, Hubacek K (2011) Comparison of bottom-up and top-down approaches to calculating the water footprints of nations, Economic Systems Research Vol 23, Issue 4

Frischknecht R, Steiner R, Braunschweig A, Egli N, Hildesheimer G (2006) Swiss Ecological Scarcity Method: The New Version 2006. Swiss Federal Office for the Environment (FOEN), Zurich and Bern, Switzerland

GEMSTAT. Global Water Quality Database; .www.gemstat.org

Goedkoop MJ, Heijungs R, Huijbregts M, De Schryver A, Struijs J, Van Zelm R (2008) ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition Report I: Characterisation; 6 January 2009, www.lcia-recipe.info.

Goedkoop M, Spriensma R (2000) The Eco-indicator 99: A Damage Oriented Method for Life Cycle Assessment: Methodology Report, 2nd ed. Pré Consultants BV, Amersfoort, The Netherlands

References III

Guinée JB (2001) Life cycle assessment: An operational guide to the iso standards. Centre for Environmental Science, Leiden University, Leiden

Guinée, J.B. (Ed.), Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., Van Oers, L., Wegener Sleeswijk, A., Suh, S.,. Udo de Haes, H.A, De Bruijn, J.A., Van Duin R., Huijbregts, M.A.J. (2002). Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards. Series: Eco-efficiency in industry and science. Kluwer Academic Publishers. Dordrecht ISBN 1-4020-0557-1

Hanafiah M, Xenopoulos M, Pfister S, Leuven RS, Huijbregts M (2011) Characterization factors for water consumption and greenhouse gas emissions based on freshwater fish species extinction. Environment Science and Technology 45 (12):5272–5278

Heijungs et al. (2008): LCA (Life Cycle Assessment) Training kit material, UNEP/SETAC LCI, available at: http://lcinitiative.unep.fr/default.asp?site=lcinit&page_id=56666AB6-E732-45F2-A89E-640951EA5F59

Hoekstra AY, Chapagain AK, Aldaya MM, Mekonnen MM (2011) The water footprint assessment manual: setting the global standard. Water Footprint Network. Enschede, the Netherlands

Hoekstra, A.Y., Mekonnen, M.M., Chapagain, A.K., Mathews, R.E. and Richter, B.D. (2012) Global monthly water scarcity: Blue water footprints versus blue water availability, PLoS ONE 7(2): e32688

Huijbregts, M.A.J., Van Zelm, R. (2009). Ecotoxicity and human toxicity. Chapter 7 in: Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., Struijs, J., De Schryver, A., Van Zelm, R. (2009): ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors, first edition.

Humbert S, Maendly R (2009) Characterization factors for damage to aquatic biodiversity caused by water use especially from dams used for hydropower. Paper presented at the LCA IX, Boston, 1 October 2009

IPCC (2007) Climate change 2007: The physical science basis. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller edn. Cambridge University Press, Cambridge, United Kingdom and New York, United States

References IV

IWMI (2007) Water for food, water for life: A comprehensive assessment of water management in agriculture. Earthscan and IWMI (International Water Management Institute), London

JRC (2011) European Commission-Joint Research Centre - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook - Recommendations for Life Cycle Impact Assessment in the European context. First edition November 2011. Luxemburg. Publications Office of the European Union; 2011; available at: http://lct.jrc.ec.europa.eu/pdf-directory/ILCD%20Handbook%20Recommendations%20for%20Life%20Cycle%20Impact%20Assessment%20in%20the%20European%20context.pdf

Kounina A, Margni M, Bayart JB, Boulay AM, Berger M, Bulle C, Frischknecht R, Koehler A, Mila-i-Canals L, Motoshita M, Núñez M, Peters G, Pfister S, Ridoutt BG, van Zelm R, Verones F, Humbert S (2012) Review of methods addressing freshwater availability in life cycle inventory and impact assessment. Int J Life Cycle Ass (in review)

Milà i Canals L, Chenoweth J, Chapagain A, Orr S, Antón A, Clift R (2009) Assessing freshwater use impacts in LCA: Part I — inventory modelling and characterisation factors for the main impact pathways. The International Journal of Life Cycle Assessment 14 (1):28-42

Motoshita M, Itsubo N, Inaba A (2010a) Damage assessment of water scarcity for agricultural use. Proceedings of 9th international conference on EcoBalance. D1-1410, The Institute of Life Cycle Assessment, Japan

Motoshita M, Itsubo N, Inaba A (2010b) Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity. The International Journal of Life Cycle Assessment 16 (1):65-73

Mutel CL, Pfister S, Hellweg S (2101) GIS-Based Regionalized Life Cycle Assessment: How Big Is Small Enough? Methodology and Case Study of Electricity Generation. Environmental Science&Technology 46, 1096-1103

Ohlsson L (2000) Water conflicts and social resource scarcity. Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere 25 (3):213-220

Oki T, Kanae S (2006) Global hydrological cycles and world water resources. Science 313 (5790):1068-1072

PE (2010) http://www.gabi-software.com.

References V

Pfister S, Koehler A, Hellweg S (2009), Assessing the Environmental Impacts of Freshwater Consumption in LCA, Environ Sc Technol 43 (11), 4098-4104.

Pfister S, Hellweg S (2009) The water "shoesize" vs. footprint of bioenergy. P Natl Acad Sci USA 106:E93-E94

Pfister S, Saner D, Koehler A (2011a) The environmental relevance of water consumption in global power production. Int J Life Cycle Ass 16: 580-591

Pfister, S. Bayer, P; Koehler, A; Hellweg, S. (2011b) Environmental impacts of water use in global crop production: hotspots and trade-offs with land use article, Environ Sc Technol, 45, 5761-5768

Pfister, S Bayer, P; Koehler, A; Hellweg, (2011c) Projected water consumption in future global agriculture: Scenarios and related impacts . Science of the Total Environment 2011, 409, 4206-4216

Pfister S, Hellweg S (2011) Surface water use – human health impacts. Report of the LC-IMPACT project (EC: FP7). Available at. http://www.ifu.ethz.ch/ESD/downloads/Uncertainty_water_LCIA.pdf

Pfister and Baumann (2012). Monthly characterization factors for water consumption and application to temporal explicit cereals inventory. Proceedings of 8th International Conference on LCA in the Agri-Food Sector, Rennes, France, 2-4 October 2012, online available at: http://www.ifu.ethz.ch/ESD/downloads/reports/Monthly_WSI_LCA_FOOD.pdf

Ridoutt BG, Pfister S (2010a) Reducing humanity's water footprint. Environ Sci Technol 44:6019-6021

Ridoutt BG, Pfister S (2010b). A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. Glob Environ Chang 20:113-120

Ridoutt BG, Pfister S (2012). A new water footprint calculation method integrating consumptive and degradative water use into a single stand-alone indicator, Int J LCA, (online).

Rockström J, Steffen W, Noone K, Persson Å, Chapin FS, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Cruzen P, Foley JA (2009) A safe operating space for humanity. Nature 461:472-475

References VI

Rost S, Gerten D, Bondeau A, Lucht W, Rohwer J, Schaphoff S (2008) Agricultural green and blue water consumption and its influence on the global water system. Water Resources Research 44 (9). doi:10.1029/2007wr006331

Shiklomanov IA, Rodda JC (2003) World water resources at the beginning of the 21st century. International hydrology series. Cambridge University Press, Cambridge

Smakhtin V, Revenga C, Döll P (2004) A Pilot Global Assessment of Environmental Water Requirements and Scarcity. Water International 29 (3):307-317

UNEP (2012) Measuring water use in a green economy. McGlade, J., Werner, B., Young, M., Matlock, M., Jefferies, D., Sonnemann, G., Aldaya, M., Pfister, S., Berger, M., Farell, C., Hyde, K., Wackernagel, M., Hoekstra, A., Mathews, R., Liu, J., Ercin, E., Weber, J.L., Alfieri, A., Martinez-Lagunes, R., Edens, B., Schulte, P., von Wirén-Lehr, S., Gee, D. ISBN: 978-92-807-3220-7

van Zelm R, Schipper AM, Rombouts M, Snepvangers J, Huijbregts MAJ (2011) Implementing Groundwater Extraction in Life Cycle Impact Assessment: Characterization Factors Based on Plant Species Richness for the Netherlands. Environmental Science and Technology 45 (2):629-635

Verones F, Hanafiah MM, Pfister S, Huijbregts MAJ, Pelletier GJ, Koehler, A (2010) Characterisation factors for thermal pollution in freshwater aquatic environments. Environ Sci Technol 44: 9364-9369

Vionnet S, Lessard L, Offutt A, Levova T, Humbert, S (2012) Quantis Water Database - Technical report – Quantis International (Bât D, Parc Scientifique, 1015 Lausanne – Suisse / www.quantis-intl.com)

Water Footprint Network (WFN, 2011) WaterStat. Enschede, the Netherlands

Wenzel, H., Hauschild, M. & Alting, L. (1997) Environmental Assessment of Products, Vol.1: Methodology, Tools and Case Studies in Product Development. Institute of Product Development, Kluwer Academic Publishers, Hingham, MA. USA.

ACKNOWLEDGMENTS AND DISCLAIMER

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** (environemntal product declaration) as uncertainties are high and consistencies among studies is generally poor
- Product category rules (**PCR**) will contribute to address this problem

WULCA

A LIFE CYCLE INITIATIVE PROJECT

END OF MATERIAL

Anne-marie.boulay@polymtl.ca

stephan.pfister@ifu.baug.ethz.ch

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

CIRAIG

ADDITIONAL MATERIAL

Authors of Training material

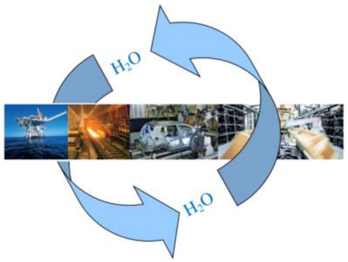
- **Stephan Pfister** is a senior research associate at ETH Zurich, focusing on the impact assessment of water consumption in Life cycle Assessment (LCA) of agriculture and power production and advancing water footprinting concepts including future assessments and international trade. For his PhD thesis 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

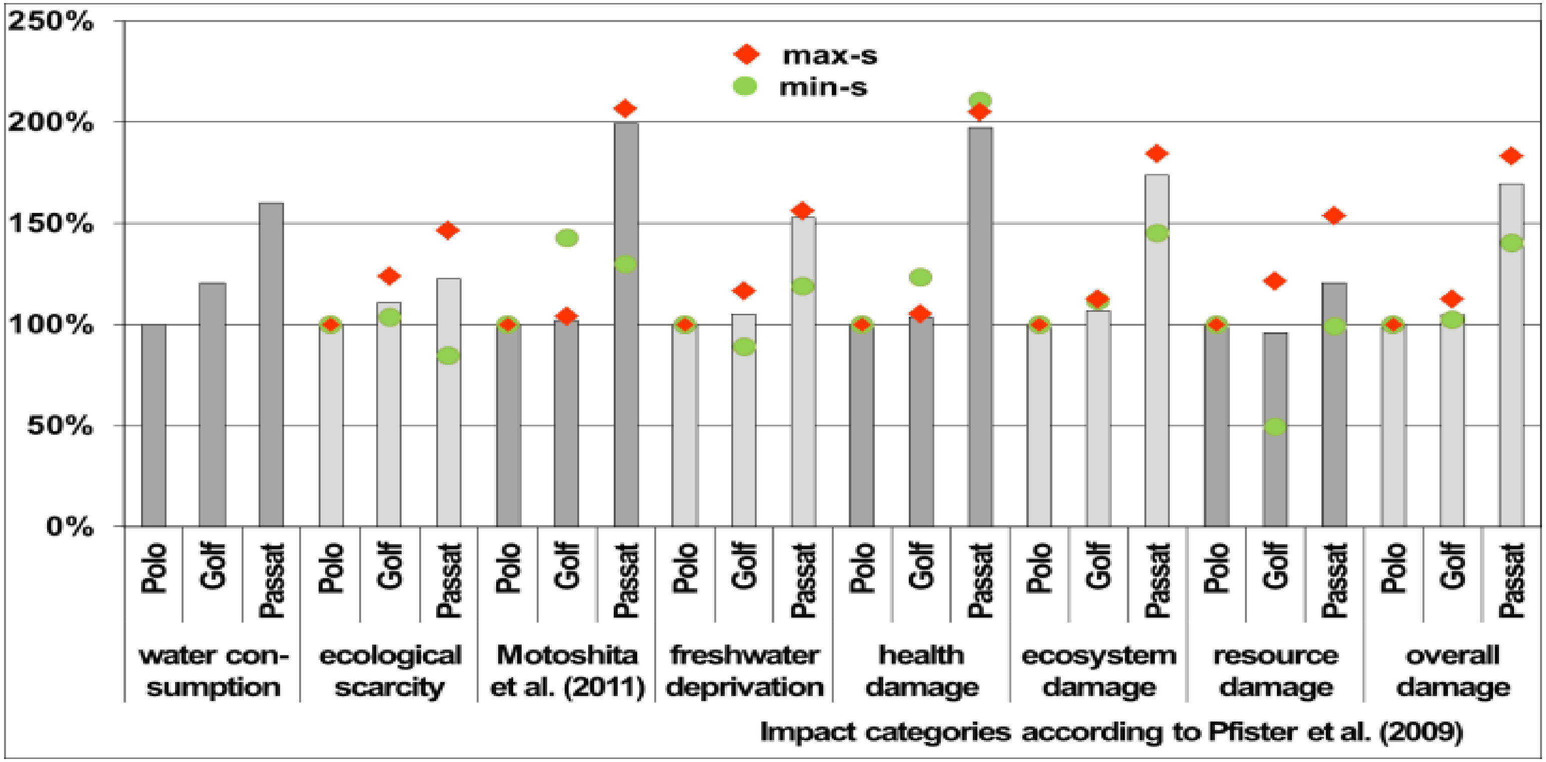


- Water footprinting in the automotive industry
  - How much water is consumed in a car's life cycle?
  - What is the impact of this water consumption?
- Procedure
  - Determine water consumption on an inventory level by means of LCA software and Volkswagen's LCI data bases
  - Geographical differentiation 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)

Acknowledgements

- Sonia Valdivia
- Maite Aldaya
- Stefanie Hellweg
- Markus Berger
- Lea Eymann
- Francesca Verones
- Jean-Baptiste Bayart
- Michael Boesch
- Rosalie van Zelm
- Masaharu Motoshita
- Sebastien Humbert
- Chris Mutel
- Sangwon Suh
- Thomas Sonderegger

Official review:

- Claudia Pena
- Yiwen Chiu
- Jean-Baptiste Bayart
- Francesca Verones
- Bruce Vigon
- Masaharu Motoshita
- Elan Theeboom
- Reinout Heijungs