The Water Footprint of Humanity

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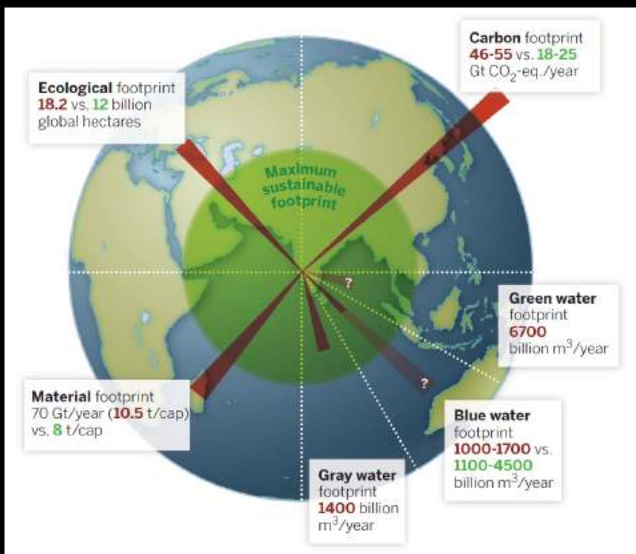
Family of footprints

- Ecological (land) footprint – how much land do we need
- Water footprint – how much water do we consume and pollute
- Carbon footprint – how much greenhouse gasses do we emit
- Material footprint – how much materials do we extract from the environment

Humanity's unsustainable environmental footprint



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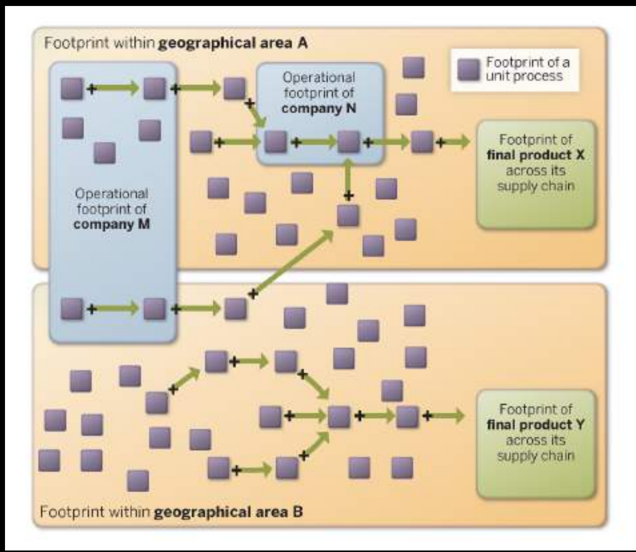
Source: Hoekstra and Wiedmann (2014) Humanity's unsustainable environmental footprint, *Science*

Footprint accounting over supply chains



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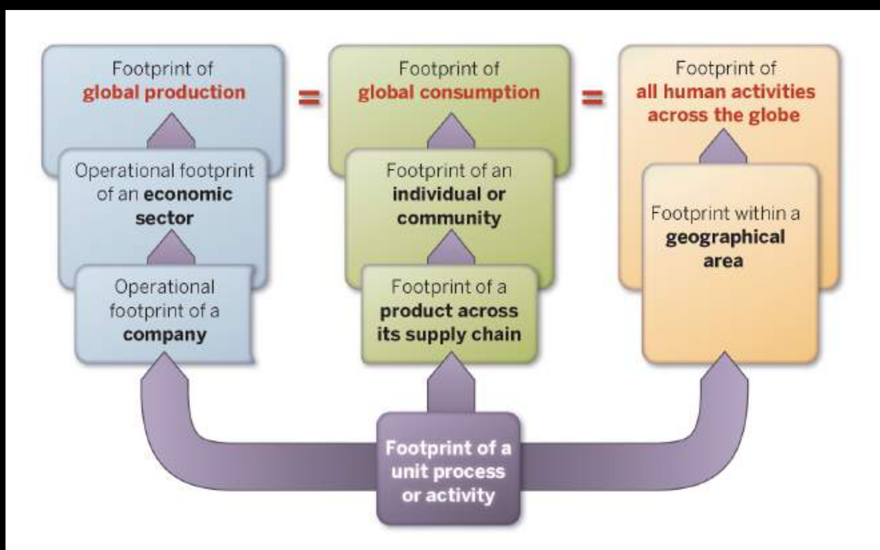
Source: Hoekstra and Wiedmann (2014) Humanity's unsustainable environmental footprint, *Science*

The relation between footprints of different entities



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Source: Hoekstra and Wiedmann (2014) Humanity's unsustainable environmental footprint, *Science*

Overview of presentation

Proceedings of the National Academy of Sciences, 109(9): 3232–3237, 2012.

- Globalization of water
- The water footprint concept
- WF of a product
- WF of a company
- Mapping the WF
- What can we do


PNAS

The water footprint of humanity

Arjen Y. Hoekstra and Mesfin M. Mekonnen

The water footprint of the average consumer in the world

3800 litre/day

3.8% of the water footprint relates to home water use

96.2% of the water footprint is ‘invisible’,
related to the products bought on the market

91.5% agricultural products, 4.7% industrial products

22% of the water footprint does not lie within the country of the consumer, but other parts of the world

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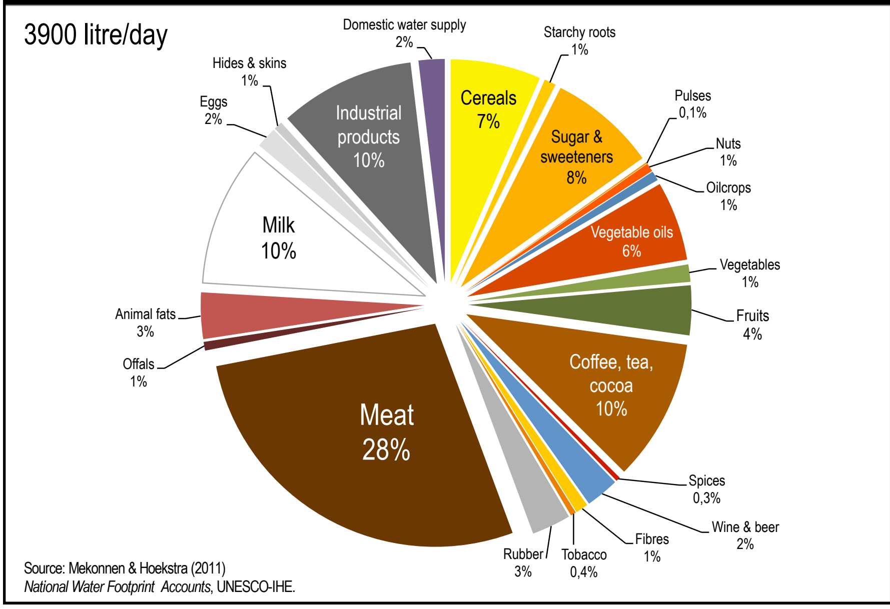
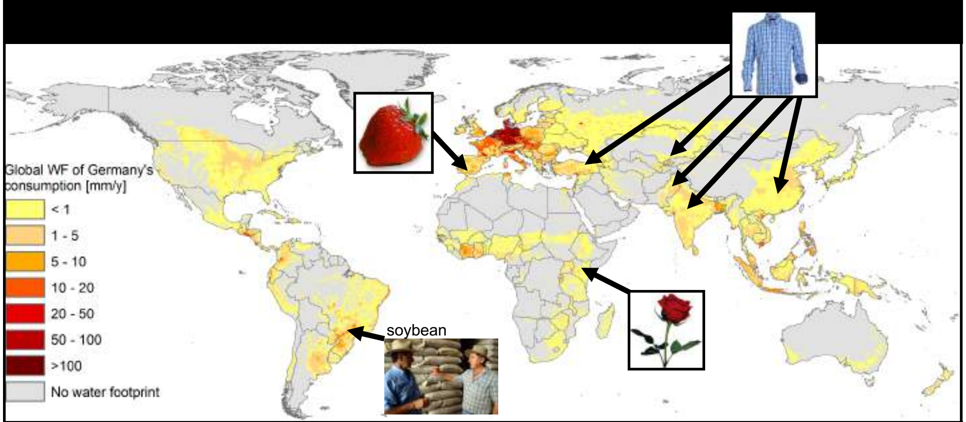
Source: Hoekstra & Mekonnen (2012) The Water Footprint of Humanity, *PNAS*

Example – the water footprint of a consumer in Germany



Global water footprint of German consumption



- 69% of Germany's water footprint is outside its own borders
- Germany ranks no.4 on list of largest net virtual water importers

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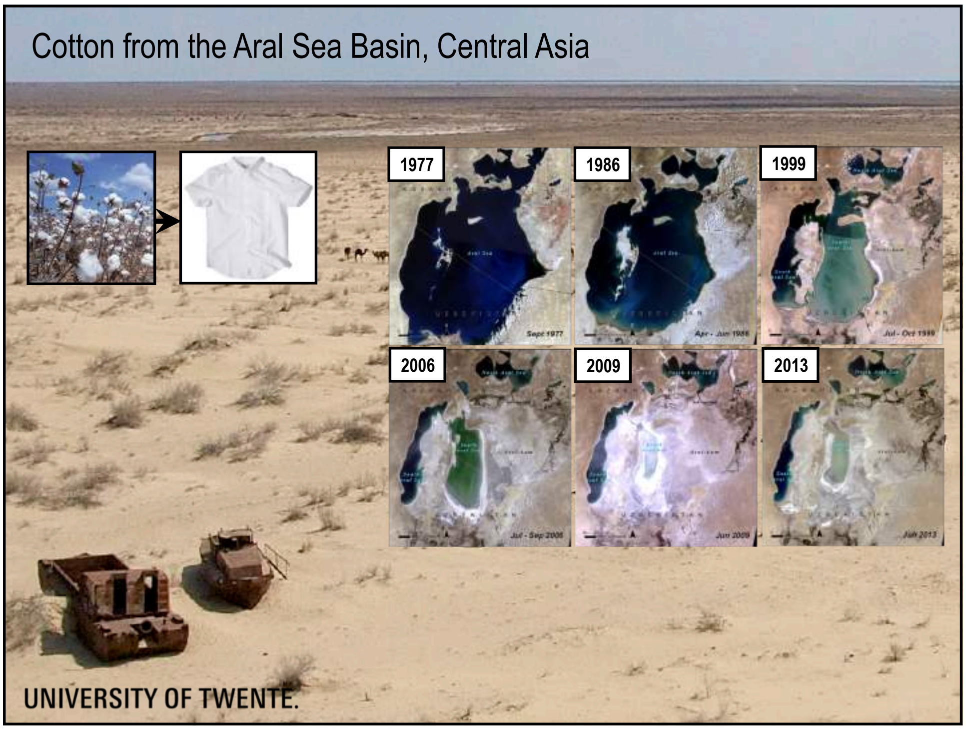
Source: Mekonnen & Hoekstra (2011) *National Water Footprint Accounts*, UNESCO-IHE.


Cotton from the Aral Sea Basin, Central Asia
1977
1986
1999
2006
2009
2013
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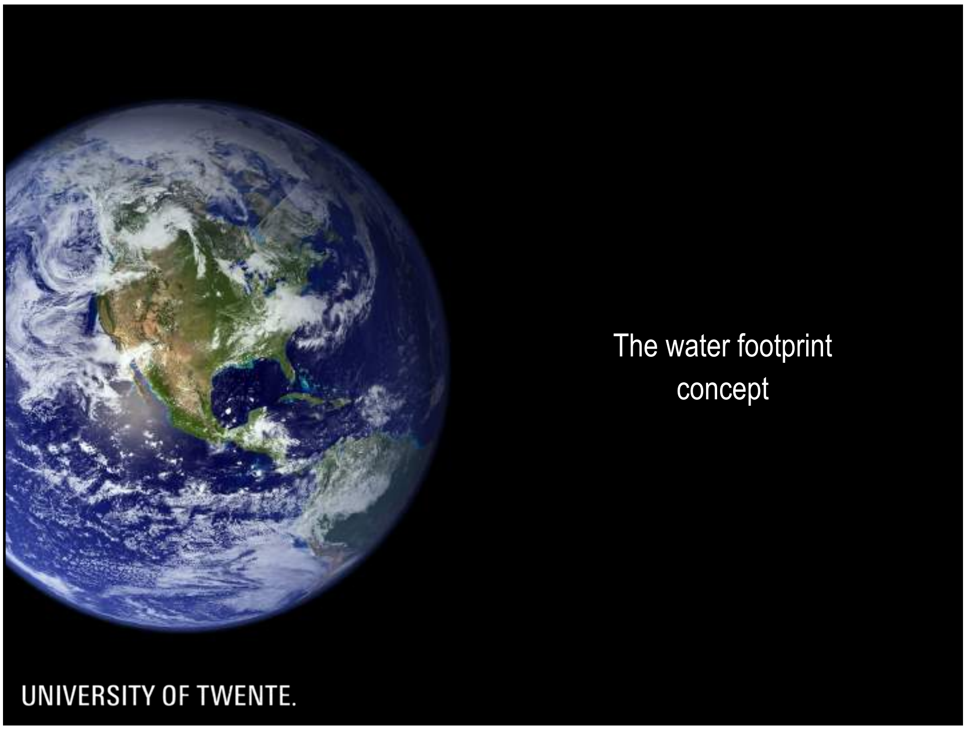
The water footprint concept
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Water footprint assessment: what's new

Broadening perspective:

- Intro of supply chain thinking in water management
- Highlighting the international dimension of water use & scarcity
- Connecting different players: governments & local water users, companies & consumers down the supply chain, investors.

What precisely is measured:

- *Net* instead of *gross* blue water abstraction
- Inclusion of green water consumption as well
- Inclusion of water pollution as well

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Source: Hoekstra et al. (2011) *The Water Footprint Assessment Manual*, Earthscan, London, UK

The water footprint concept

► The WF is an indicator of water use that looks at both direct and indirect water use of a consumer or producer.

► Water use is measured in terms of water volumes consumed (evaporated or otherwise not returned) or polluted per unit of time.

► The water footprint is a geographically and temporally explicit indicator; it shows water volumes used but also where and when.

► A water footprint can be calculated for a process, a product, a consumer, group of consumers (e.g. municipality, province, state or nation) or a producer (e.g. a public organization, private enterprise).

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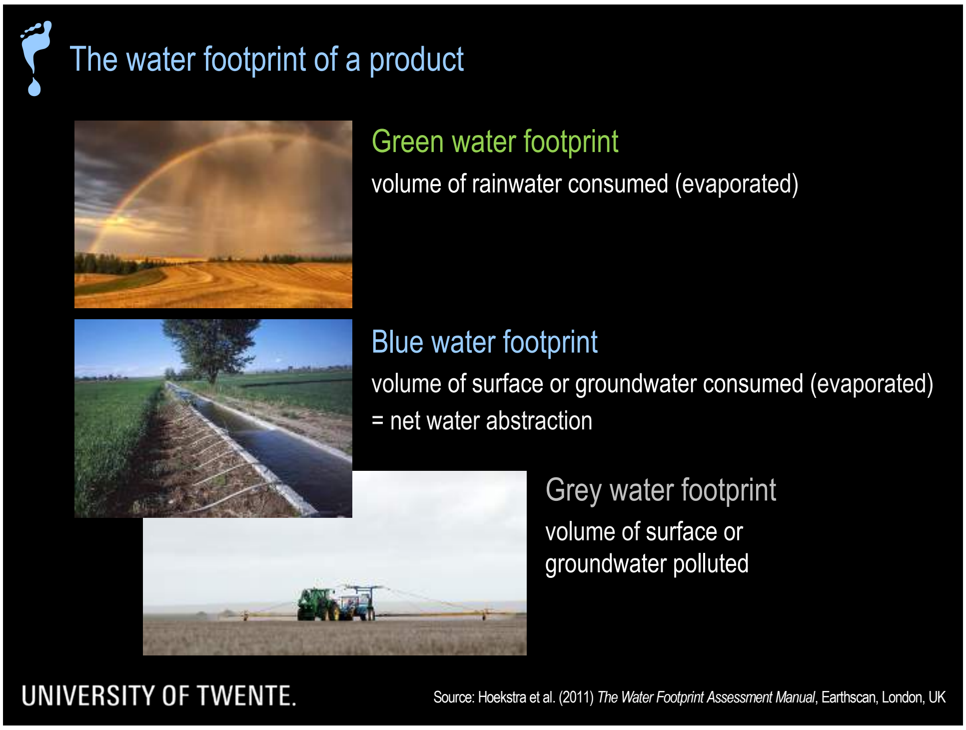
Source: Hoekstra et al. (2011) *The Water Footprint Assessment Manual*, Earthscan, London, UK



The water footprint of a product
Green water footprint
volume of rainwater consumed (evaporated)
Blue water footprint
volume of surface or groundwater consumed (evaporated)
= net water abstraction
Grey water footprint
volume of surface or
groundwater polluted
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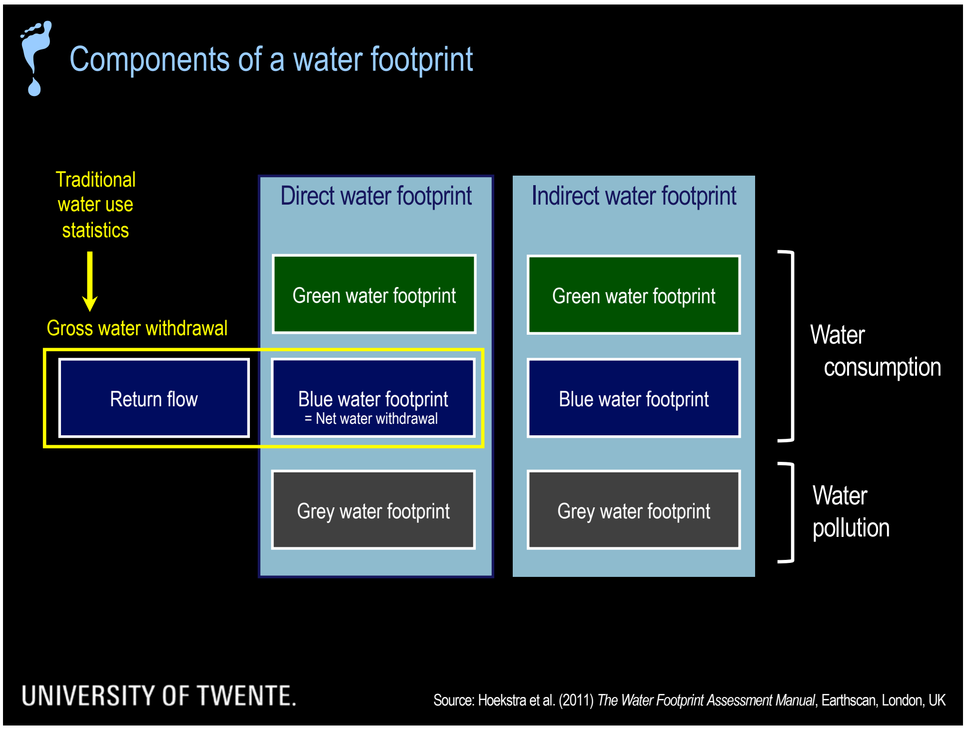
Source: Hoekstra et al. (2011) The Water Footprint Assessment Manual, Earthscan, London, UK



Components of a water footprint
Traditional
water use
statistics
Gross water withdrawal
Return flow
Direct water footprint
Green water footprint
Blue water footprint
= Net water withdrawal
Grey water footprint
Indirect water footprint
Green water footprint
Blue water footprint
Grey water footprint
Water
consumption
Water
pollution
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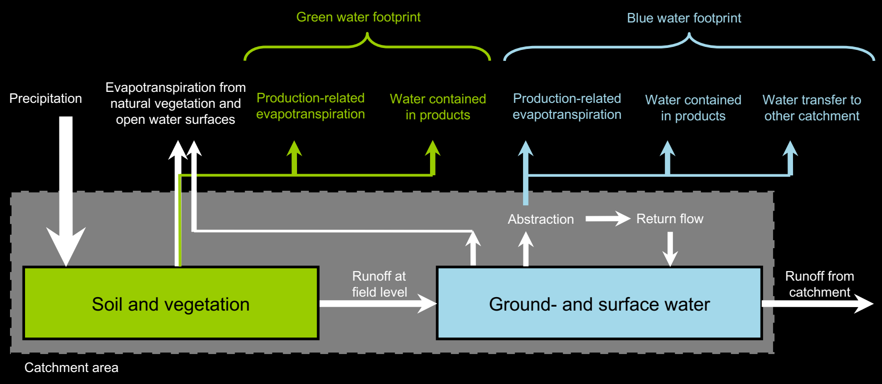
Source: Hoekstra et al. (2011) The Water Footprint Assessment Manual, Earthscan, London, UK

The green and blue water footprint in relation to the water balance of a catchment area



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Source: Hoekstra et al. (2011) *The Water Footprint Assessment Manual*, Earthscan, London, UK

Green water footprint vs. green water availability

Assessment per catchment:

Green water availability =

total evapotranspiration (ET) from the land area in the catchment
– ET from land reserved for nature
– ET from non-nature areas that cannot be made productive

Green water scarcity = Green water footprint / green water availability

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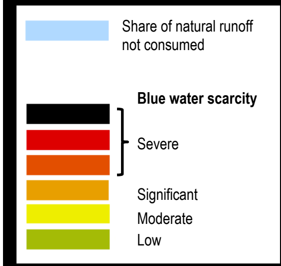
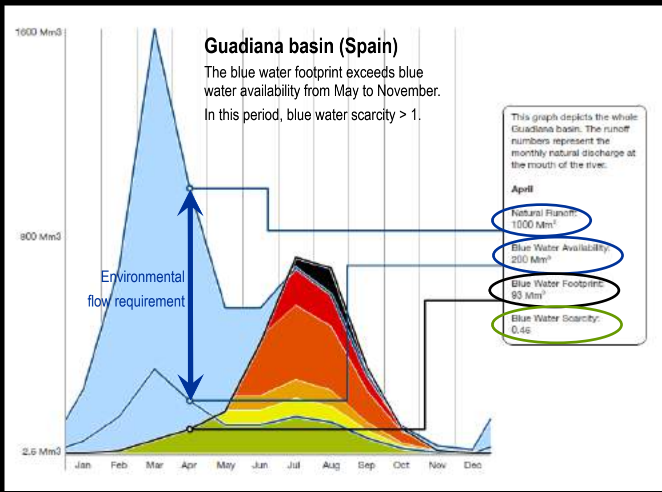
Source: Hoekstra et al. (2011) *The Water Footprint Assessment Manual*, Earthscan, London, UK

Blue water footprint vs. blue water availability





Environmental flow requirements
To be established at catchment level, on a monthly basis.

Presumptive standard:
EFR = 80% of natural runoff
(Richter et al., 2011)

Replace this estimate when better local estimates are available

Blue water availability = Natural runoff – Environmental flow requirement

Blue water scarcity = Blue water footprint / Blue water availability

The grey water footprint in relation to the assimilation capacity in the catchment

Substance intake (IN)
= Water abstraction volume × c_{act}

Substance output (OUT)
= Effluent volume × c_{effl}

Load = OUT- IN

Freshwater flow R

Critical load = $(c_{max} – c_{nat}) \times R$

Grey water footprint = (Load / Critical load) × R

Max. sustainable grey water footprint = R

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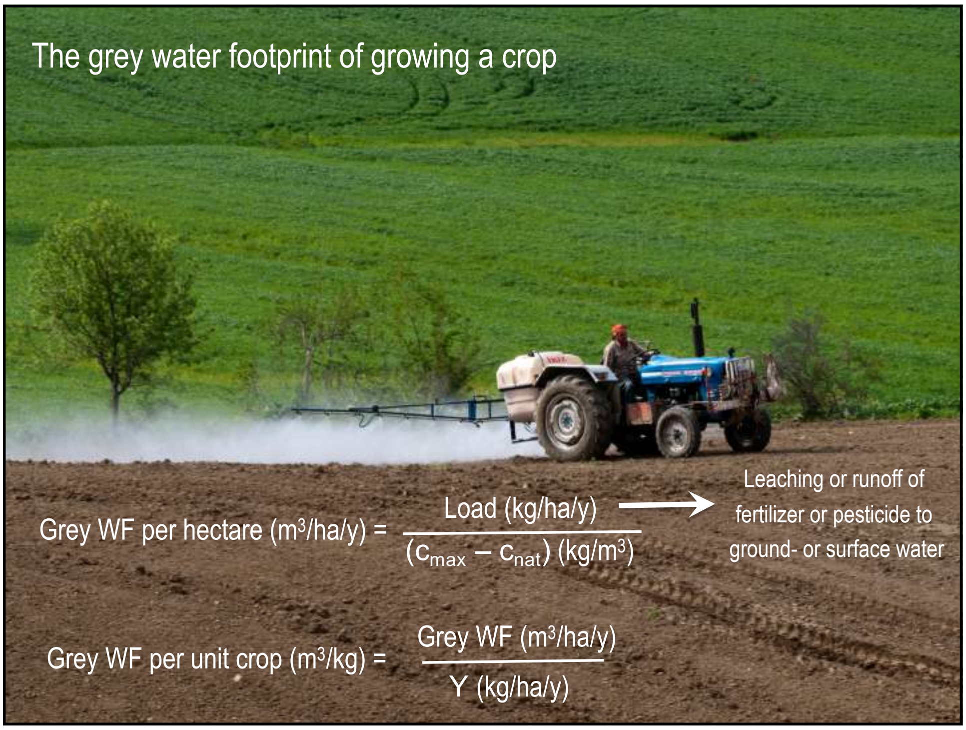
Source: Hoekstra et al. (2011) *The Water Footprint Assessment Manual*, Earthscan, London, UK



Water Footprint Assessment (WFA)

- Phase 1: Setting goals and scope →
- Phase 2: Water footprint accounting →
- Phase 3: Water footprint sustainability assessment →
- Phase 4: Water footprint response formulation

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Source: Hoekstra et al. (2011) *The Water Footprint Assessment Manual*, Earthscan, London, UK

Environmental sustainability
Social equity
Economic efficiency
Supply security

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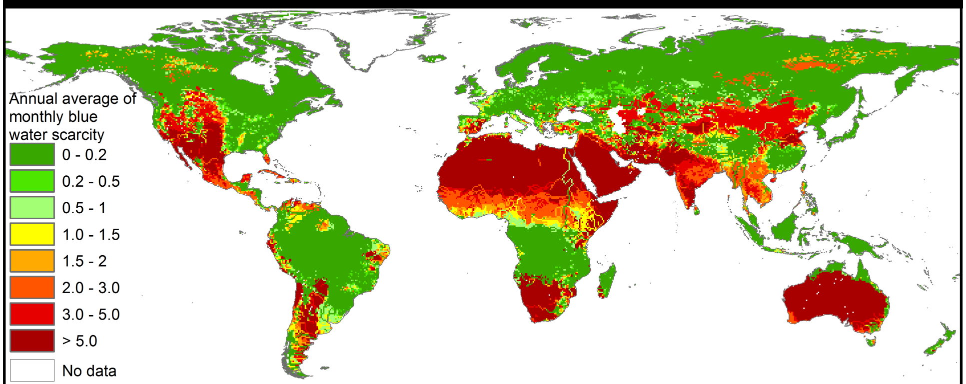
The water footprint of humanity: not sustainable

Blue water scarcity = blue WF / maximum sustainable blue WF



Source: Mekonnen & Hoekstra (2016) *Science Advances*, 2(2): e1500323

We need to agree on water footprint caps per river basin (specified per month)

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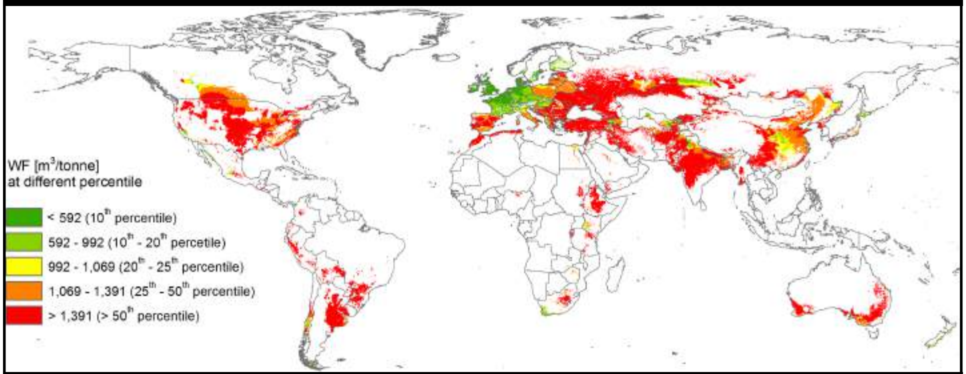
The water footprint of humanity: not efficient

Spatial differences in the water footprint of wheat



Reduction of water footprints of crops to benchmark levels set by the best 25% of global production, will result in a global water saving of 40%.

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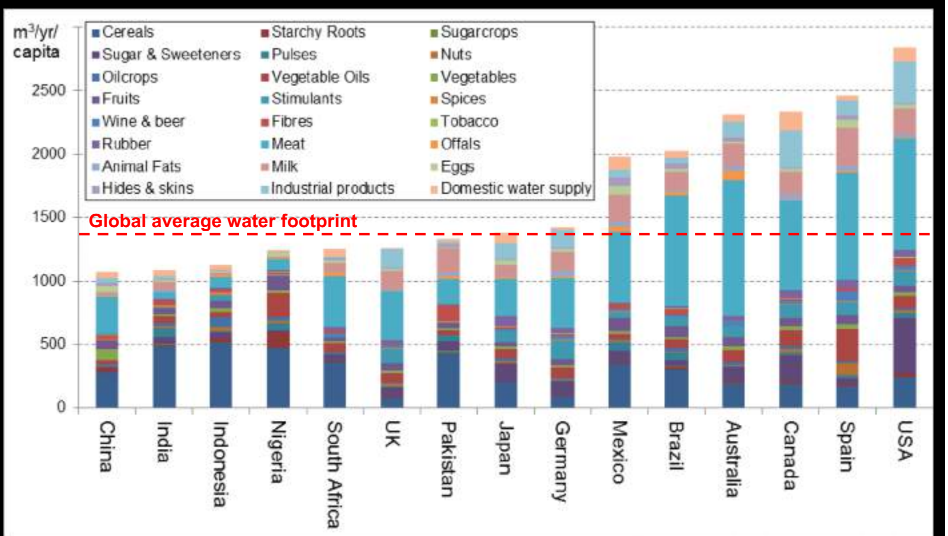
Source: Mekonnen & Hoekstra (2014)

The water footprint of humanity: not fairly distributed



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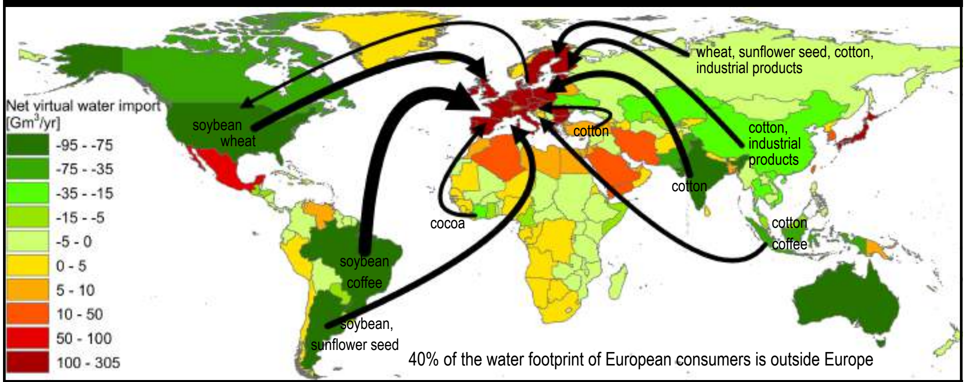
Source: Hoekstra & Mekonnen (2012) The Water Footprint of Humanity, *PNAS*

The water footprint of humanity: international dependencies

Example European Union



Source: Hoekstra & Mekonnen (2012) The Water Footprint of Humanity, *PNAS*

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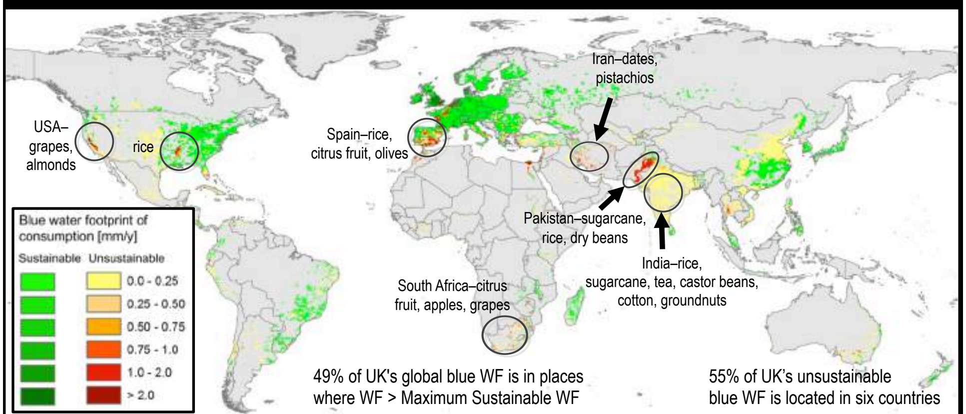
The sustainability of UK's global blue water footprint



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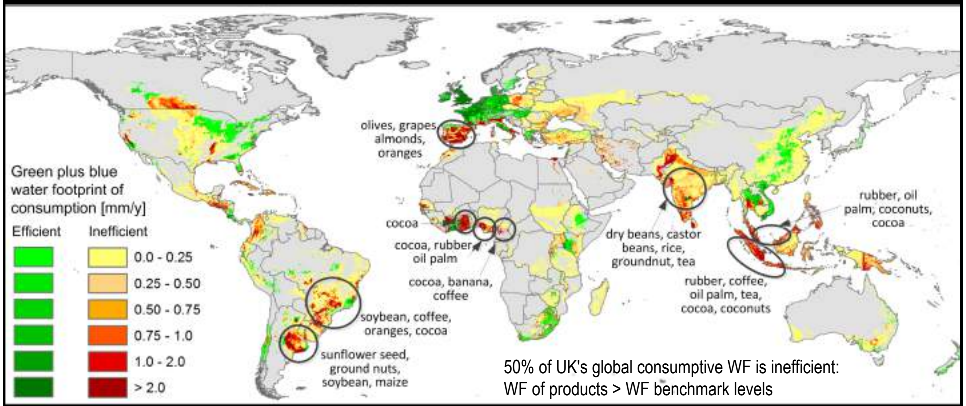
Source: Hoekstra & Mekonnen (2016)

The efficiency of UK's global consumptive water footprint



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Source: Hoekstra & Mekonnen (2016)

The water footprint
of a product

examples for cotton, food & energy

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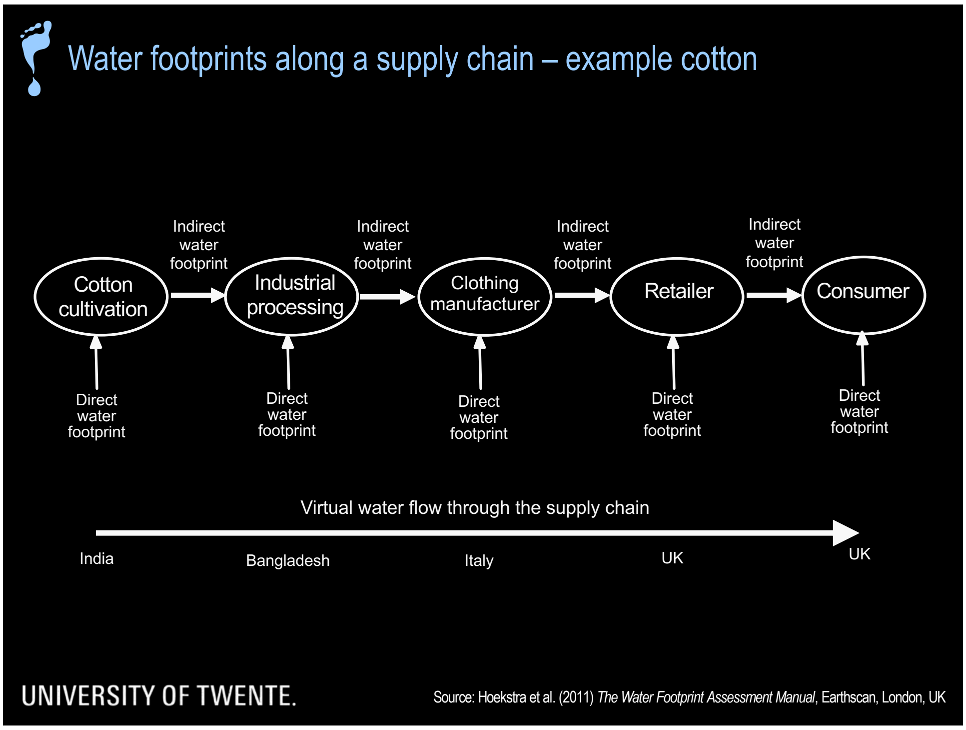
Water footprints along a supply chain – example cotton
Indirect water footprint
Indirect water footprint
Indirect water footprint
Indirect water footprint
Cotton cultivation
Industrial processing
Clothing manufacturer
Retailer
Consumer
Direct water footprint
Direct water footprint
Direct water footprint
Direct water footprint
Direct water footprint
Virtual water flow through the supply chain
India
Bangladesh
Italy
UK
UK
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Source: Hoekstra et al. (2011) The Water Footprint Assessment Manual, Earthscan, London, UK


2500 litres of water
for 1 cotton shirt

Benchmarking the water footprint of seed cotton

- The three most important cotton producing countries in the Aral Sea Basin – Uzbekistan, Turkmenistan and Tajikistan – have a green–blue water footprint of about 5,000 litres/kg of seed cotton

- If they would manage to reduce the water footprint to the global 20-percentile benchmark of 1,820 litres/kg, the region would reduce cotton-related water use by nearly a factor of three.

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Source: Hoekstra (2013) *The Water Footprint of Modern Consumer Society*, Routledge, London, UK

The water footprint of different natural fibres

	litre/kg
Abaca fibre	22700
Cotton lint	9100
Sisal fibre	7800
Agave fibre	6500
Ramie fibre	4500
Flax fibre	3800
Hemp fibre	2700
Jute fibre	2600

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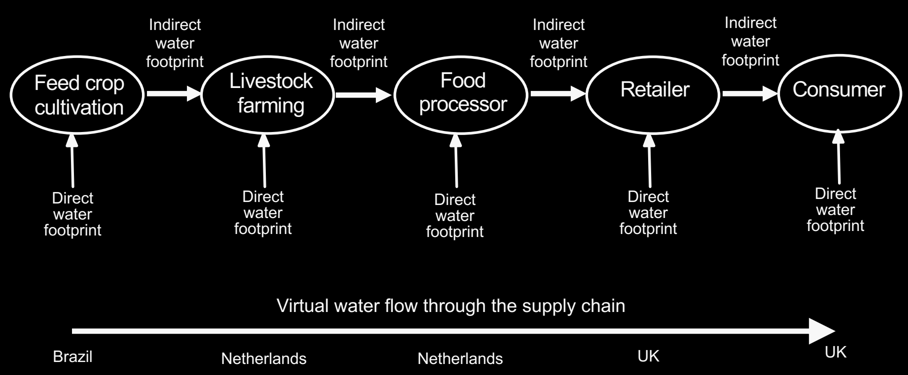
Source: Hoekstra (2013) *The Water Footprint of Modern Consumer Society*, Routledge, London, UK

Water footprints along a supply chain – example meat



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Source: Hoekstra et al. (2011) *The Water Footprint Assessment Manual*, Earthscan, London, UK

The water footprint of food

Global average water footprint

	litre/kcal
starchy roots	0.5
cereals	0.5
sugar crops	0.7
pulses	1.1
vegetables	1.3
fruits	2.1
pork	2.2
poultry	3.0
beef	10.2

Source: Mekonnen & Hoekstra (2012) A global assessment of the water footprint of farm animal products, *Ecosystems*

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Meat versus vegetarian diet

Industrialised countries:

Meat diet	kcal/day	litre/kcal	litre/day
Animal origin	950	2.5	2375
Vegetable origin	2450	0.5	1225
Total	3400		3600

Source: Hoekstra (2013) The Water Footprint of Modern Consumer Society, Routledge, London, UK.

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Meat versus vegetarian diet

Industrialised countries:

Meat diet	kcal/day	litre/kcal	litre/day	Vegetarian diet	kcal/day	litre/kcal	litre/day
Animal origin	950	2.5	2375	Animal origin	300	2.5	750
Vegetable origin	2450	0.5	1225	Vegetable origin	3100	0.5	1550
Total	3400		3600	Total	3400		2300

Source: Hoekstra (2013) The Water Footprint of Modern Consumer Society, Routledge, London, UK.

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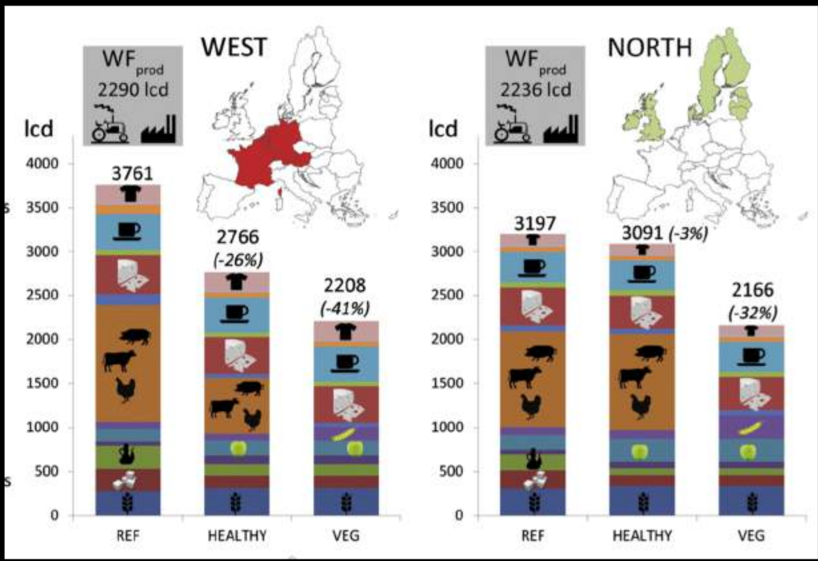
The water efficiency of our food – example Europe



Source: Vanham et al. (2013)

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The two separate worlds of water and energy

- The water sector is becoming more energy-intensive
  - desalination
  - pumping deeper groundwater
  - large-scale (inter-basin) water transfers
- The energy sector is becoming more water-intensive
  - shale oil & gas (fracking)
  - tar sands & oil / kerogen shales
  - biomass

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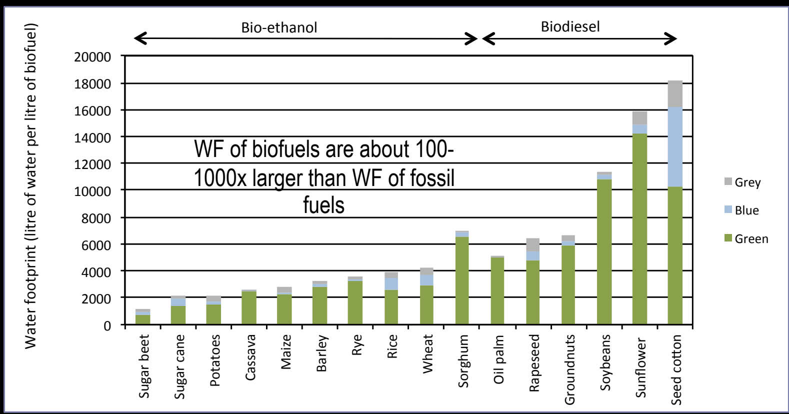
Source: Hoekstra (2013) *The Water Footprint of Modern Consumer Society*, Routledge, London, UK

The water efficiency of energy supply

The energy sector is becoming increasingly water-intensive due to the growing use of shale oil & gas, tar sands, and biomass



Source: Mekonnen & Hoekstra (2011)

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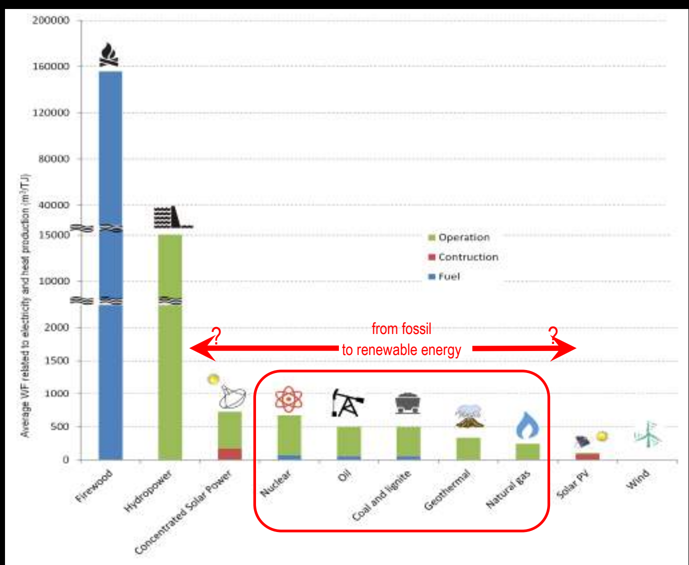
The water efficiency of electricity



Source: Mekonnen, Gerbens-Leenes & Hoekstra (2015)

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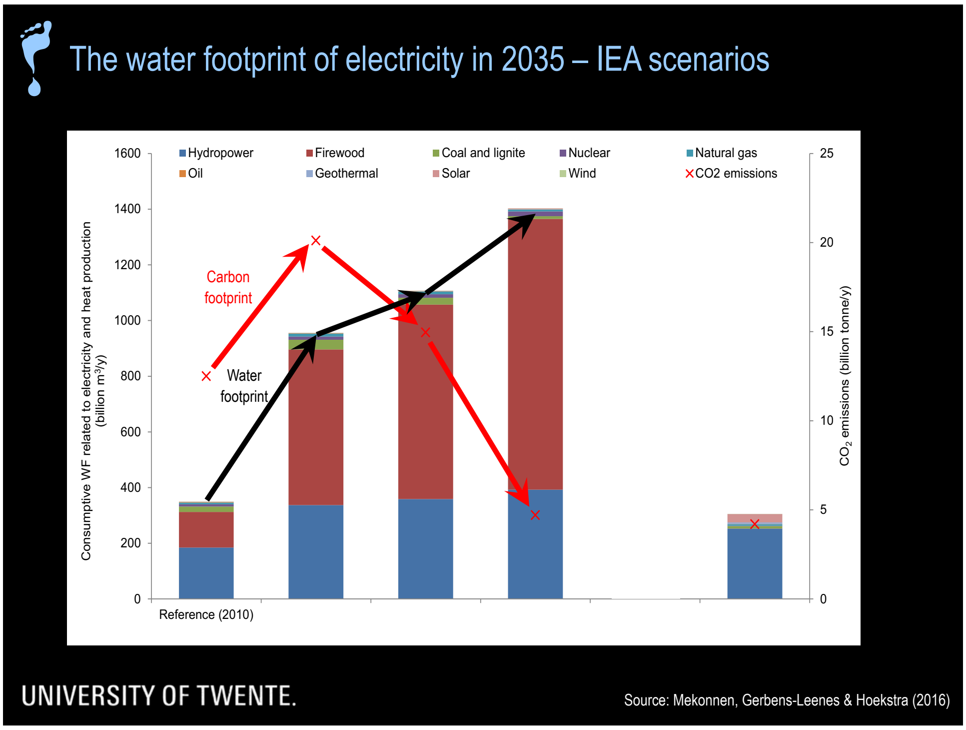
The water footprint of electricity in 2035 – IEA scenarios
1600
1400
1200
1000
800
600
400
200
0
Consumptive WF related to electricity and heat production (billion m³/y)
Hydropower
Firewood
Coal and lignite
Nuclear
Natural gas
Oil
Geothermal
Solar
Wind
CO2 emissions
Carbon footprint
Water footprint
Reference (2010)
25
20
15
10
5
0
CO2 emissions (billion tonne/y)
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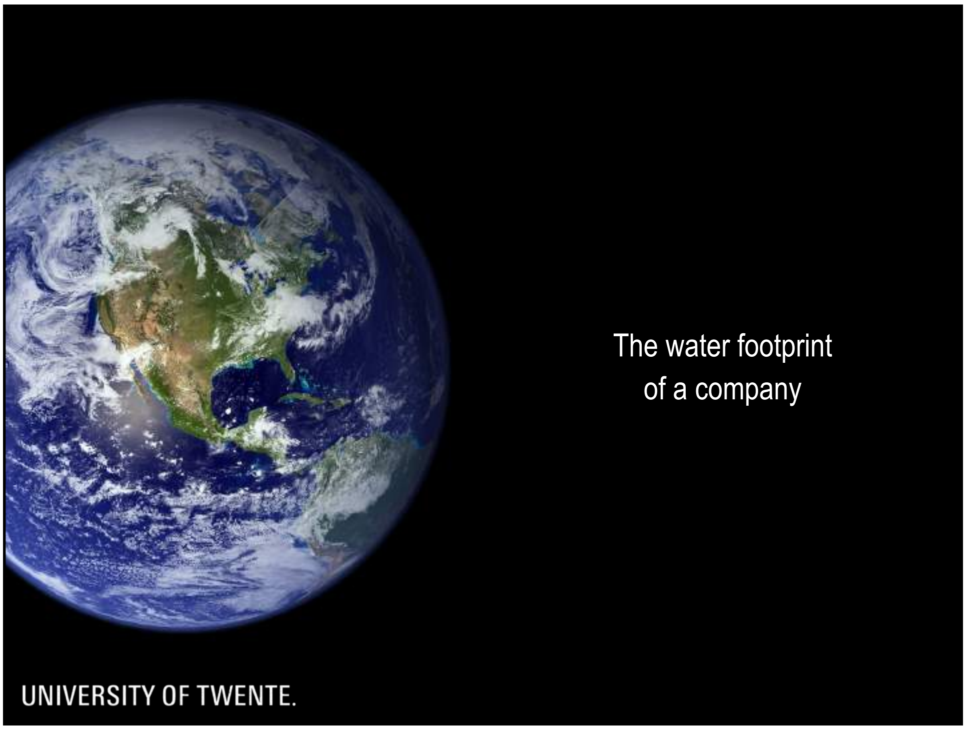
Source: Mekonnen, Gerbens-Leenes & Hoekstra (2016)


The water footprint of a company
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The Coca Cola Company

New Delhi, 4 Oct 2006

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Water footprint of a Coke

Water footprint of a 0.5 litre PET-bottle coke
as produced in the Dongen factory, the Netherlands

0.44 litre water content
27.6 litre for sugar
5.3 litre for PET bottle and closure
3.0 litre for other ingredients & overheads

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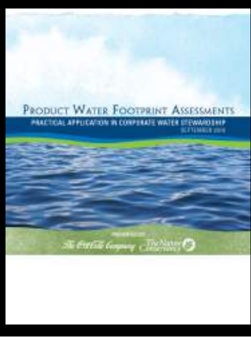
36 litre total



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Water Footprint Assessment – Examples from business

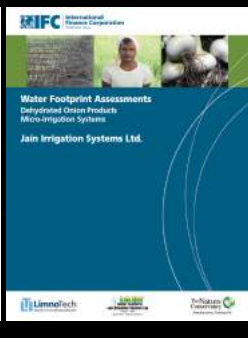
TATA
Steel, Automotive, Chemicals, Power

C&A
Apparel

CocaCola, SABMiller, Unilever, Nestlé
Food & Beverage

UPM
Pulp & Paper

Jain Irrigation, India
Water supply technology



Water footprint geographically

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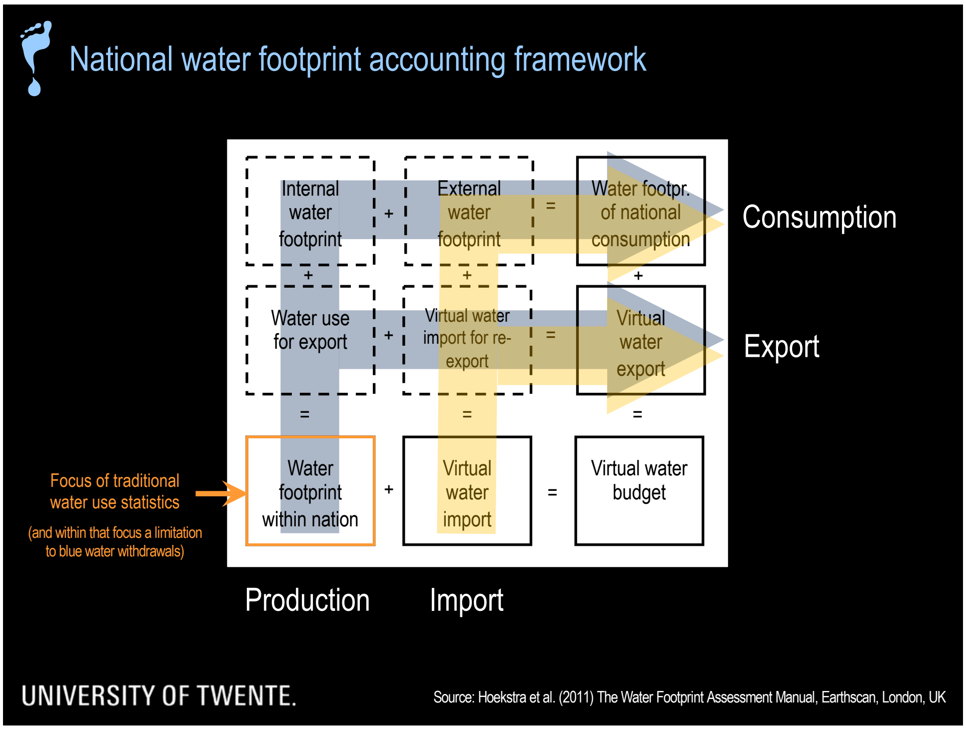
National water footprint accounting framework
Internal water footprint
External water footprint
Water footpr. of national consumption
Water use for export
Virtual water import for re-export
Virtual water export
Water footprint within nation
Virtual water import
Virtual water budget
Consumption
Export
Production
Import
Focus of traditional water use statistics
(and within that focus a limitation to blue water withdrawals)
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Source: Hoekstra et al. (2011) The Water Footprint Assessment Manual, Earthscan, London, UK


International virtual water flows
Virtual water flow (m3/yr) =
Trade volume (ton/yr) × Product water footprint (m3/ton)
Global trade data:
UN Statistics Division, New York
FAOSTAT, FAO, Rome

National water footprint from production and consumption perspective

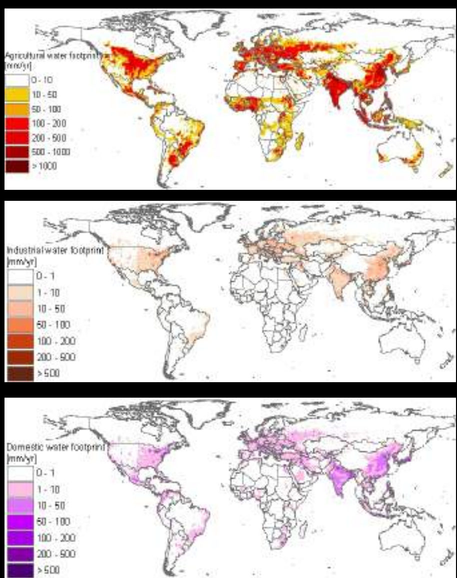
Country	Water footprint (billion m³/year)	
	from the perspective of production	from the perspective of consumption
Egypt	69	95
Jordan	1.4	8.3
Japan	42	175
Germany	58	117
Netherlands	5.8	23
UK	29	75
China	1207	1368
India	1182	1145
Australia	137	45
Canada	161	72
USA	1053	821

Source: Mekonnen & Hoekstra (2011) *National Water Footprint Accounts*, UNESCO-IHE.

Traditional statistics on water use, but then restricted to water withdrawal → WF within a nation

WF of national consumption

The water footprint of humanity – by sector



Source: Hoekstra & Mekonnen (2012) The Water Footprint of Humanity, *PNAS*

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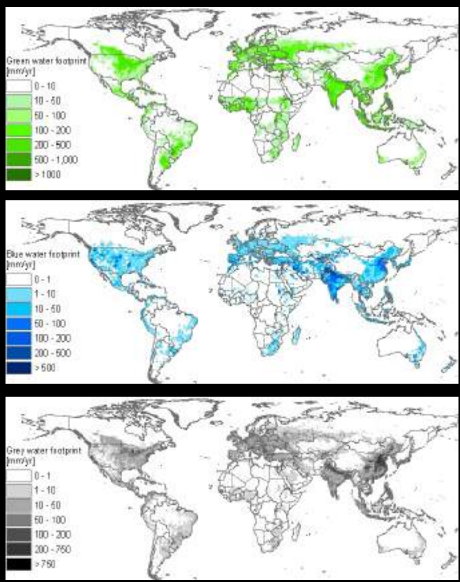
The water footprint of humanity – by colour



Source: Hoekstra & Mekonnen (2012)
The Water Footprint of Humanity, *PNAS*

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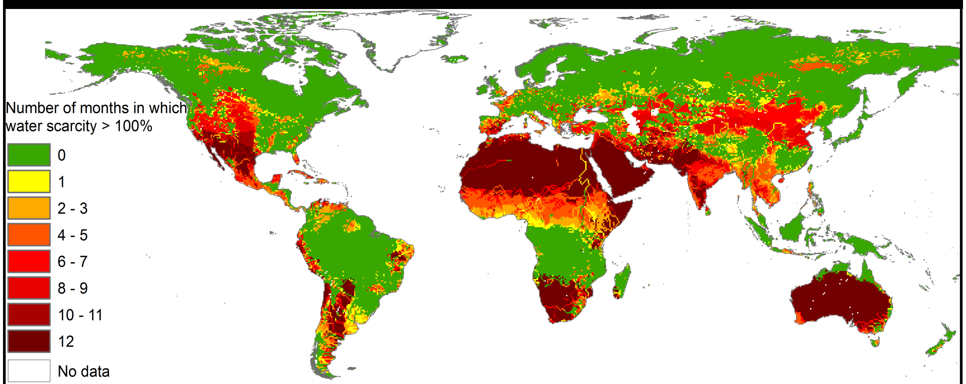
Number of months with blue water scarcity exceeding 100%

Blue water scarcity = blue water footprint / blue water availability



Source: Mekonnen & Hoekstra (2016) *Science Advances*, 2(2): e1500323

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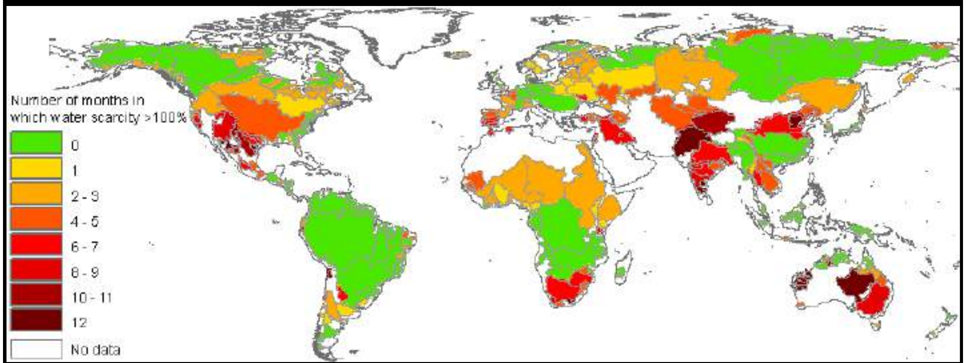

Source: Hoekstra et al. (2012) Global monthly water scarcity: blue water footprints versus blue water availability, *PLoS ONE*

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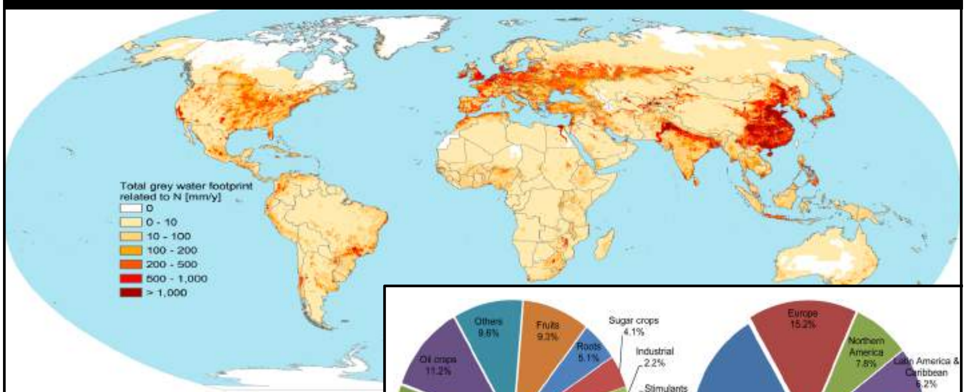
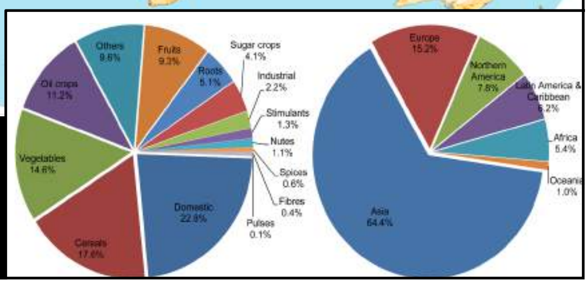
Nitrogen-related grey water footprint in the world





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N leaching from global croplands

Global N inputs to and outputs from croplands per crop category (10^6 tonne/year). Period: 2002-2010.

Balance term	Cereals	Veget-ables	Oil crops	Fruits	Roots & tubers	Sugar crops	Pulses	Nuts	Other crops[1]	Total
Artificial fertilizer	60	5.8	11	4.3	3.0	2.6	0.8	0.5	8.7	96
Manure	12	4.2	5.5	3.1	1.9	0.5	0.6	0.3	9.4	38
Bio-fixation	5.3	0.2	25	0.2	0.2	0.1	2.2	0.03	0.7	34
Atmospheric N deposition	6.7	0.6	2.3	0.5	0.5	0.2	0.6	0.1	1.3	13
N supply in irrigation water	5.3	0.4	1.3	0.6	0.2	0.4	0.2	0.1	1.6	10
Total N inputs	**90**	**11**	**45**	**8.7**	**5.7**	**3.9**	**4.4**	**1.0**	**22**	**191**
N removed with harvested crops	31	0.8	15	0.9	1.0	0.5	1.6	0.02	12	63
N removed with crop residue	12	0.2	4.7	0.3	0.1	0.1	0.8	0.01	1.0	20
Total N removed with crop and crop residues	**43**	**1.0**	**20**	**1.2**	**1.1**	**0.5**	**2.4**	**0.0**	**12.5**	**82**
N budget (available for gaseous & leaching loss)	46	10	24	7.5	4.6	3.4	2.0	1.0	9.2	108
Erosion	8.8	0.7	2.9	0.9	0.8	0.4	0.9	0.1	2.2	18
NH_3 volatilization	5.1	0.6	1.1	0.4	0.3	0.2	0.1	0.04	0.5	8.3
Denitrification (N_2)	24	3.5	9.9	2.5	1.4	1.0	0.7	0.3	1.6	45
N_2O emission	0.4	0.04	0.2	0.1	0.1	0.03	0.1	0.01	0.1	1.0
NO	0.6	0.04	0.2	0.05	0.05	0.02	0.1	0.01	0.2	1.2
N leaching	**7.1**	**5.3**	**10**	**3.6**	**2.0**	**1.7**	**0.1**	**0.5**	**4.6**	**35**
Total N outputs	**90**	**11**	**45**	**8.7**	**5.7**	**3.9**	**4.4**	**1.0**	**21.7**	**191**
Leaching from anthropogenic sources[2]	**5.7**	**4.8**	**3.7**	**3.0**	**1.7**	**1.3**	**0.04**	**0.4**	**3.9**	**24**

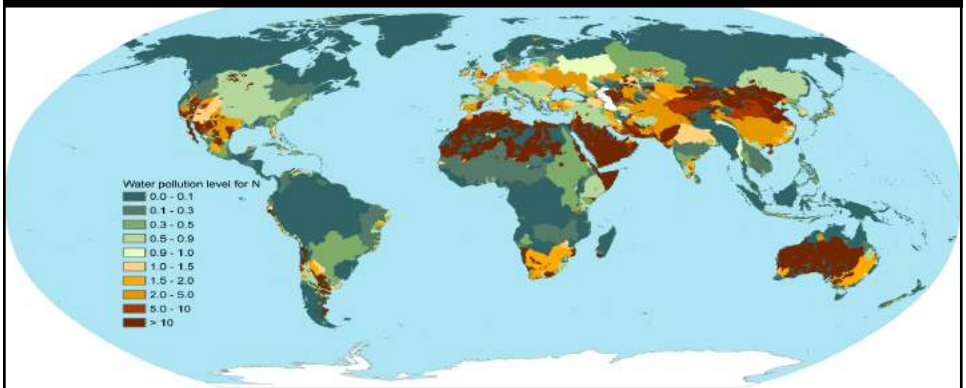
[1] Including fodder crops, coffee, tea, cocoa, spices and fibre crops.

[2] The leaching from anthropogenic sources is calculated as a fraction of total N leaching.

Source: Mekonnen & Hoekstra (2015)

Nitrogen-related grey water pollution level

Water pollution level = grey WF / maximum sustainable grey WF



Source: Mekonnen & Hoekstra (2015)

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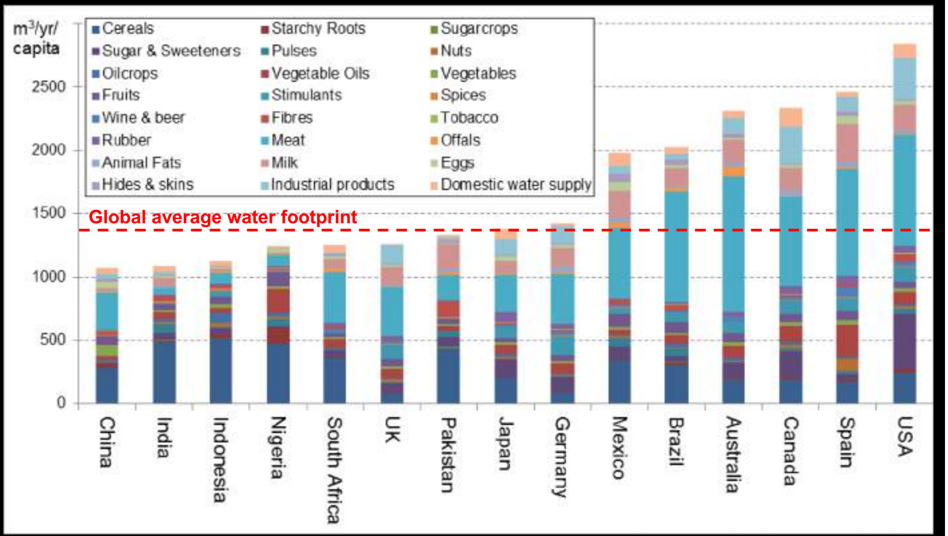
Water footprint of national consumption



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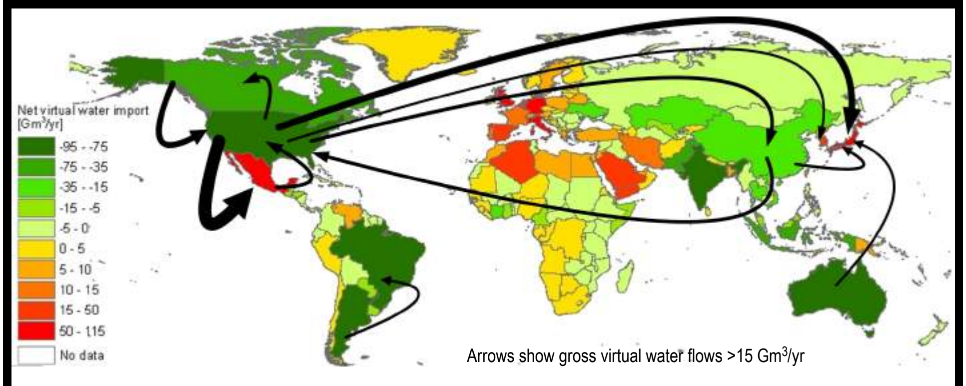
Source: Hoekstra & Mekonnen (2012) The Water Footprint of Humanity, *PNAS*

National virtual water balances



Source: Hoekstra & Mekonnen (2012) The Water Footprint of Humanity, *PNAS*

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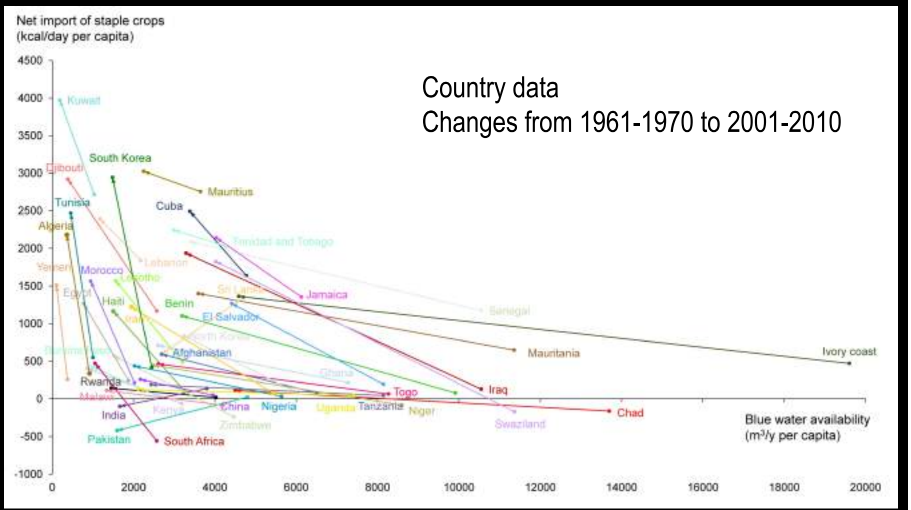
Net import of staple crops as function of blue water availability



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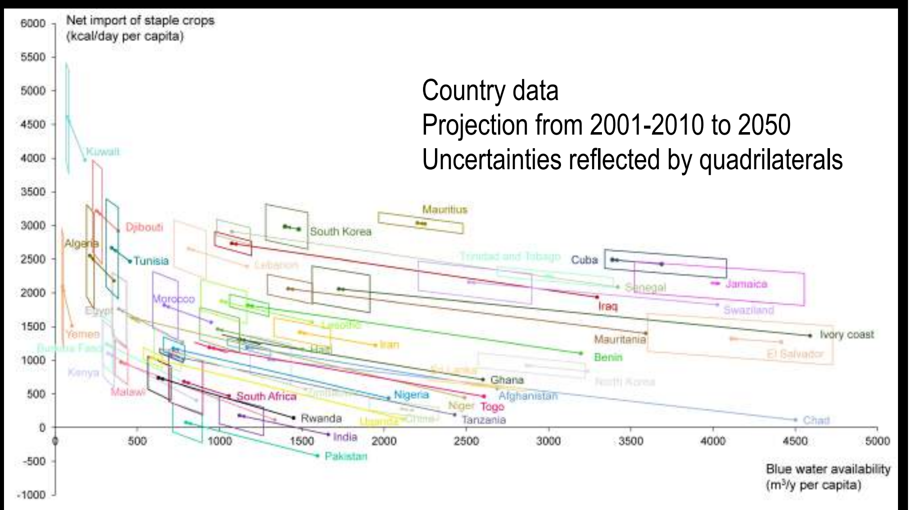
Chouchane et al. (2018)

Net import of staple crops as function of blue water availability



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Chouchane et al. (2018)

What can we do?

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Water footprint reduction: what can we do?

- Towards full water recycling in industries: zero blue water footprint
- Towards full recycling of materials and heat: zero grey water footprint

- Make rainwater more productive: lower green water footprint
- Towards supplementary or deficit irrigation & application of precision irrigation techniques: lower blue water footprint
- Towards organic or precision farming: zero grey water footprint

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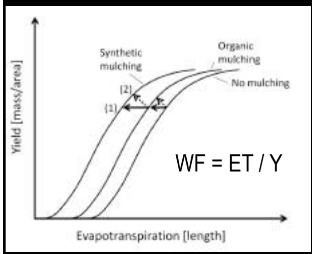
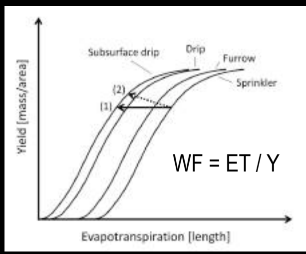
The effect of mulching & irrigation on ET, Y and WF

Mulching



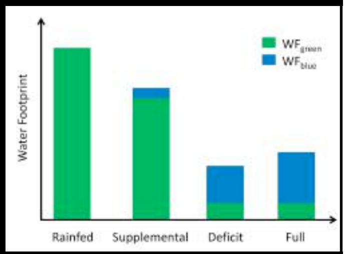
(1) Reduced soil evaporation
(2) Increased Y because of enhanced soil structure, and reduced erosion & weed growth

Irrigation technique



(1) Reduced soil evaporation
(2) Increased Y because of increased plant transpiration

Irrigation strategy



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Hoekstra (2015)

How overexploitation in a water-stressed river basin (A) can be solved by increasing water productivity in a water-abundant basin (B)

unsustainable

Parameter	Unit	Current situation	
		Basin A	Basin B
Max. sustainable water footprint	Water units / unit of time	50	250
Water footprint	Water units / unit of time	100	200
Production	Product units / unit of time	100	100
Water footprint per product unit	Water units / product unit	1	2
Water productivity	Product units / water unit	1	0.5

Source: Hoekstra (2013) *The Water Footprint of Modern Consumer Society*, Routledge, London, UK

inefficient

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Water footprint reduction: an interplay of actors

Consumers and consumer & environmental organizations push businesses and governments to address water use and impacts along supply chains.

Some businesses act voluntarily in an early stage, driven by consumers or investors.

Governments support frontrunners in businesses and implement regulations.

International cooperation, through UN and other institutions.

UNIVERSITY OF TWENTE. Source: Hoekstra (2013) *The Water Footprint of Modern Consumer Society*, Routledge, London, UK

Reducing humanity's water footprint – Consumers

Reduction of the direct water footprint:
- water saving toilet, shower-head, etc.

"Save water in the supermarket"

Reduction of the indirect water footprint:
- change consumption pattern
- choose the sustainable version of products

Asking product transparency from businesses and regulation from governments

UNIVERSITY OF TWENTE. Source: Hoekstra (2013) *The Water Footprint of Modern Consumer Society*, Routledge, London, UK

Reducing humanity's water footprint – Companies

Shared terminology & calculation standards

– Global Water Footprint Standard →

Product transparency

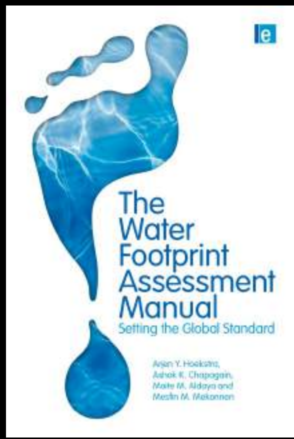
– water footprint reporting / disclosure

– labelling of products

– certification of businesses

Quantitative footprint reduction targets

– using process & product WF benchmarks



The Water Footprint Assessment Manual
Earthscan, London, UK, 2011

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Source: Hoekstra (2013) *The Water Footprint of Modern Consumer Society*, Routledge, London, UK

Reducing humanity's water footprint – Investors

Reduce risk of investments:

- physical risk formed by water shortages or pollution.
- risk of damaged corporate image
- regulatory risk
- financial risk

Demand accounting and substantiated quantitative water footprint reduction targets from companies.

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Sources: Morrison et al., 2009; Pegram et al, 2009; Hoekstra et al., 2011

Reducing humanity's water footprint – Government

Embed water footprint assessment in national water policy making.

Promote coherence between water and other governmental policies: environmental, agricultural, energy, trade, tax, foreign policy.

Reduce the own organizational water footprint
- reduce the water footprint of public services.

Promote product transparency
- support or force businesses to make annual water footprint accounts and to implement water footprint reduction measures.
- e.g. through promoting a water label for water-intensive products;
- e.g. through water-certification of businesses.

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Wise water governance

- water footprint caps by river basin
- water footprint benchmarks by product
  - product labeling →
  - certification of industries
  - water disclosure
- fair water footprint shares by consumer
  - national water footprint reduction targets


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Water hub
From Guardian Sustainable Business
Will we ever see water footprint labels on consumer products?
Displaying water inputs on consumer items is an idea floated frequently, but is it any closer to becoming reality?
Will Henley
Guardian Professional, Friday 23 August 2013 16.11 BST
Jump to comments (5)
On average it takes 15,400 litres of water to make 1kg of beef. Photograph: Bon Appetit/Alamy

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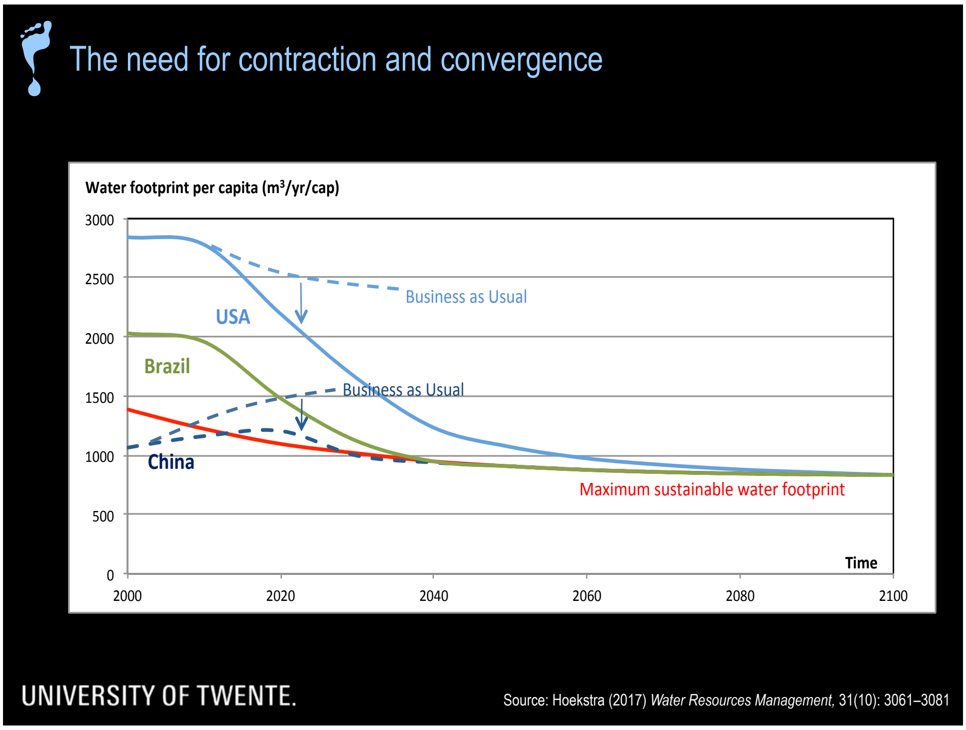
The need for contraction and convergence
Water footprint per capita (m³/yr/cap)
3000
2500
2000
1500
1000
500
0
2000
2020
2040
2060
2080
2100
Time
USA
Business as Usual
Brazil
Business as Usual
China
Maximum sustainable water footprint
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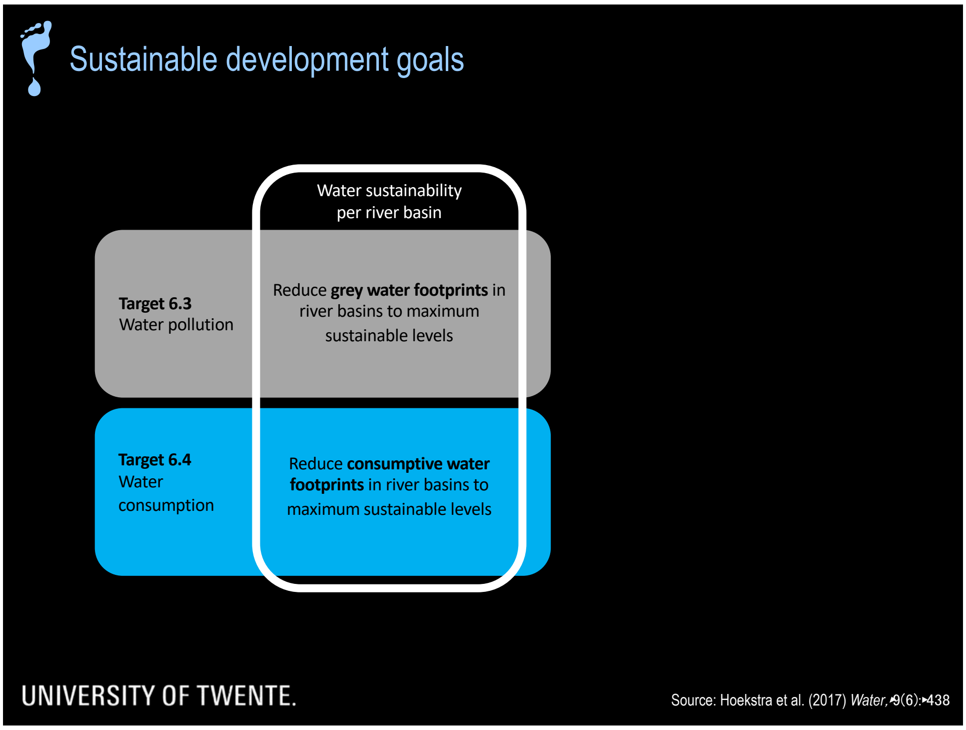
Source: Hoekstra (2017) Water Resources Management, 31(10): 3061–3081


Sustainable development goals
Water sustainability per river basin
Target 6.3
Water pollution
Reduce grey water footprints in river basins to maximum sustainable levels
Target 6.4
Water consumption
Reduce consumptive water footprints in river basins to maximum sustainable levels
UNIVERSITY OF TWENTE.
Source: Hoekstra et al. (2017) Water, 9(6): 438

Sustainable development goals

	Water sustainability per river basin	Water use efficiency per process/product
Target 6.3 Water pollution	Reduce **grey water footprints** in river basins to maximum sustainable levels	Reduce **grey water footprints** of production processes down to benchmark levels
Target 6.4 Water consumption	Reduce **consumptive water footprints** in river basins to maximum sustainable levels	Reduce **consumptive water footprints** of production processes down to benchmark levels

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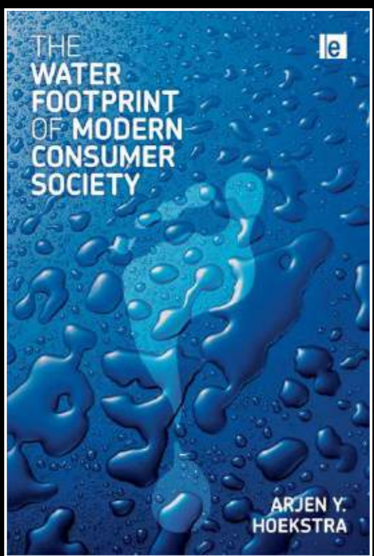
Source: Hoekstra et al. (2017) *Water*, 9(6): 438



Further reading

- Water for food, feed, fuel, fibre or flower
- Water footprint caps by river basin
- Water footprint benchmarks by product
- Fair water footprint shares by nation

Wise water governance =
smart spatial planning & informed agricultural, energy, tax, trade and foreign policy

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