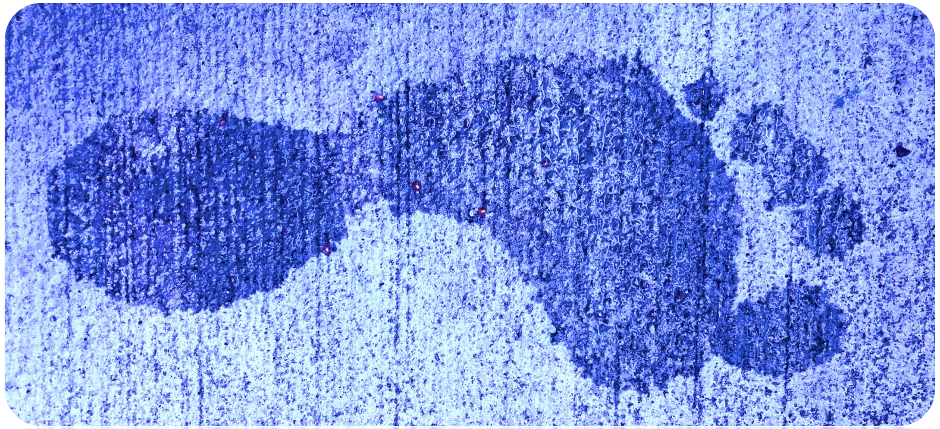
# Water Resources Engineering and Management

(CIVIL-466, A.Y. 2024-2025)

5 ETCS, Master course



Lecture 11-3: Water footprint and virtual water network

**Prof. P. Perona**

Platform of hydraulic constructions

# The use of water colors it !

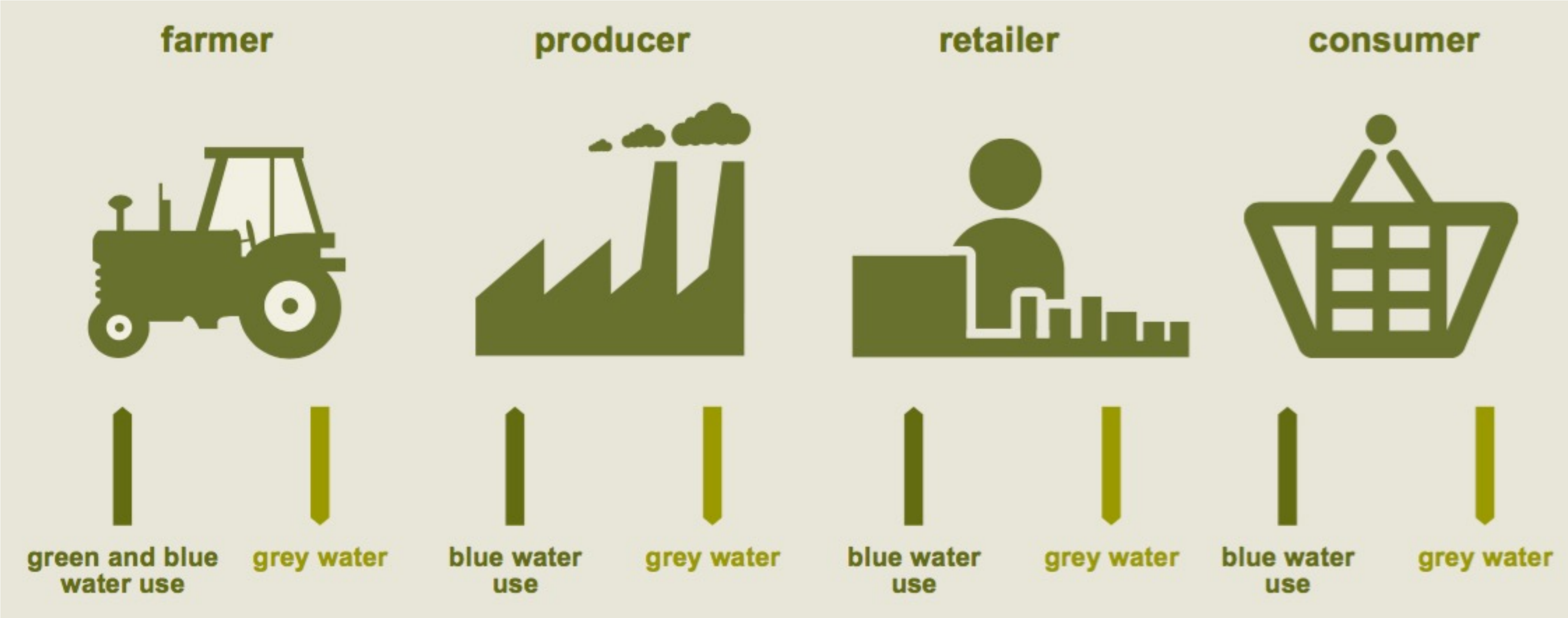
Blue water (rivers, lakes, glaciers, etc.)

Green water (forests, soil moisture, cultures, etc.)

Grey water(domestic use, commercial, industrial, etc.)

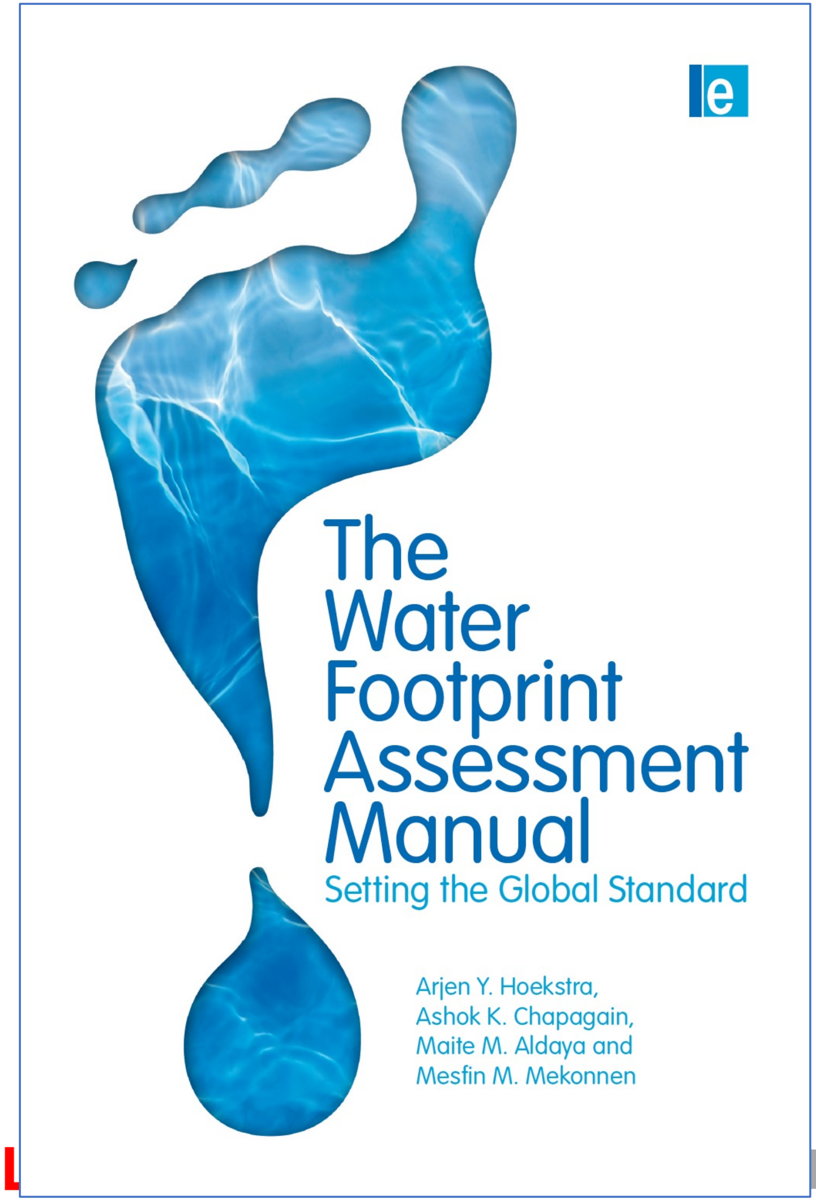
# Water footprint

Concept proposed by Allen (1980) and later developed by Hoeckstra et al. (1998)

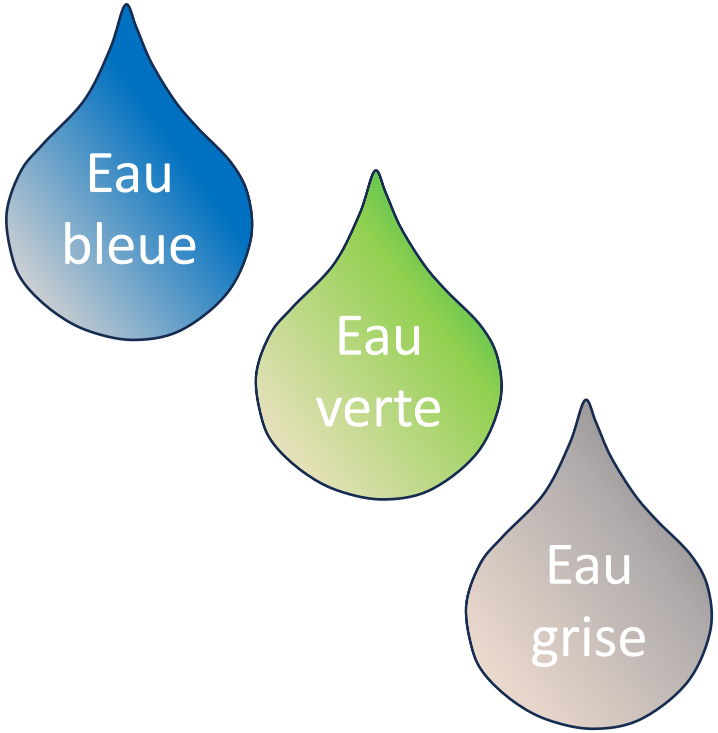



The exit from any process is always grey water!

# What does water footprint really measure?




How do we calculate the blue, green and gray water footprints *(Hoeckstra et al.,1998)*?



# Blue water footprint


$WF_{blue}$ = *Blue water evaporation* + Blue water incorporation + *Lost return flows*

[volume/time]

The blue water footprint measures the amount of water available over a given period that is consumed (in other words, that is not immediately returned to the same river basin).

# Green water footprint


$WF_{green}$ = *Green water evaporation* + Green water incorporation

[volume/time]

The green water footprint measures the volume of rainwater consumed during the production process that is not transformed into run-off or deep infiltration.

# Grey water footprint


$$WF_{grey} = \frac{L}{C_{max} - C_{nat}}$$

[volume/time]

The grey water footprint measures the degree of freshwater pollution associated with a process step in terms of the volume of freshwater required to assimilate the pollutant load compared to the existing natural ambient water quality.

# Global water footprint into a single indicator

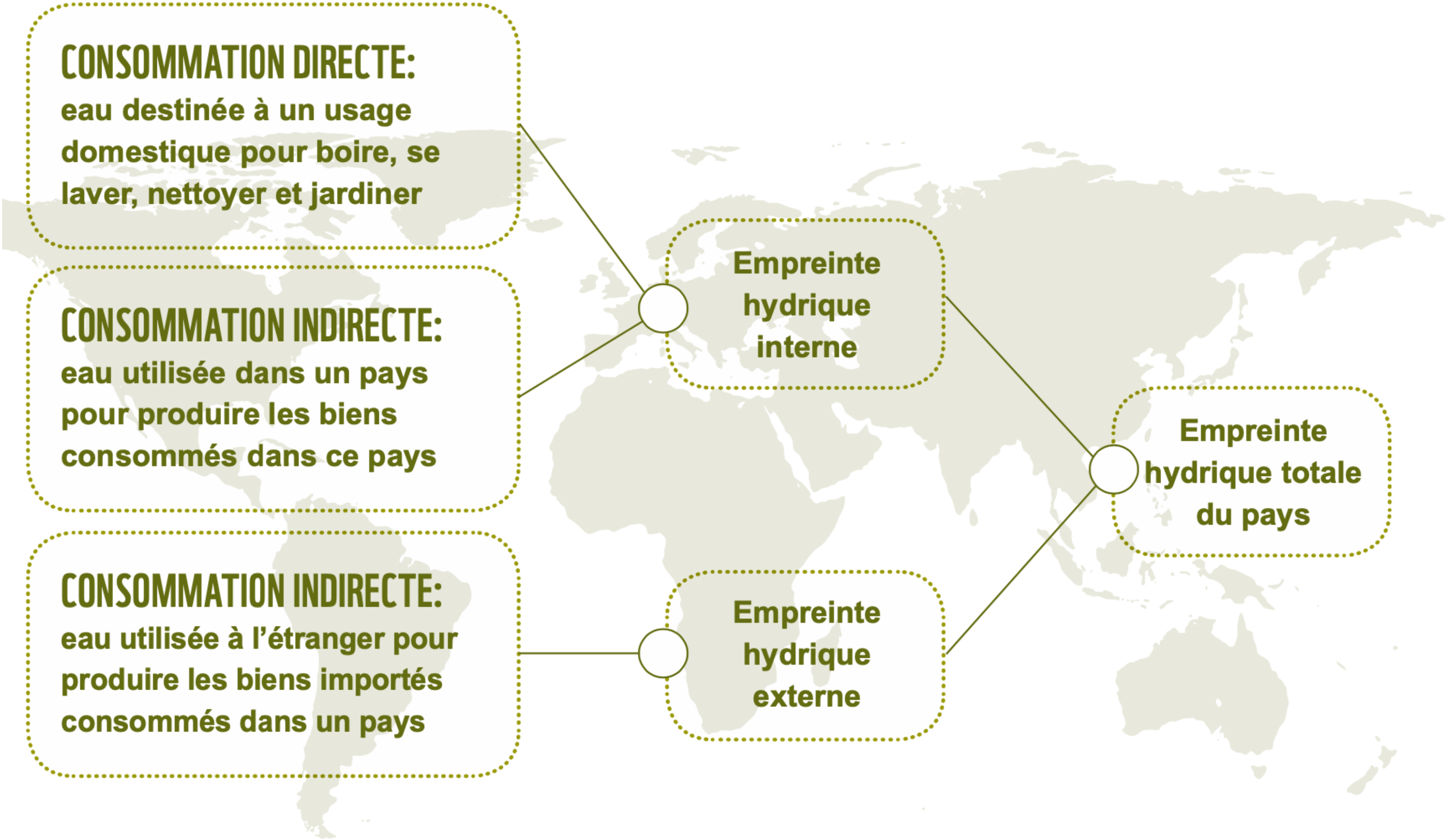


= Blue water + Green water + Grey water

$$EH_{proc} = EH_{proc,bleue} + EH_{proc,verte} + EH_{proc,gris}$$

Hoekstra et al., WFP assessment Manual, 2011

# Which water uses do affect water footprint?

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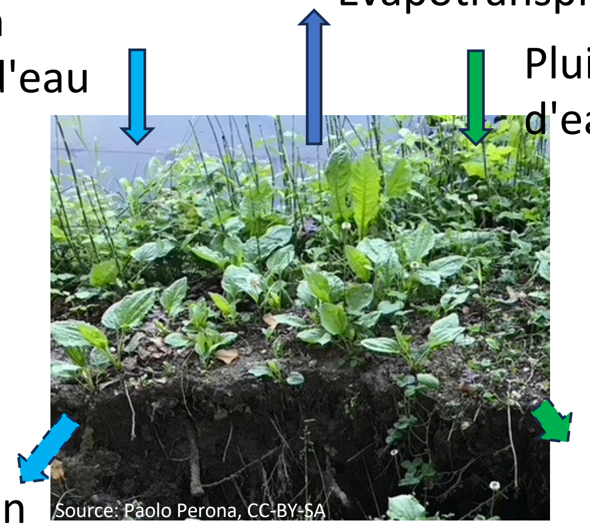
# Example: water footprints for crop production



Vous êtes chargé de calculer les empreintes bleue, verte et grise d'un système de production agricole. Vous disposez des paramètres suivants:

- Production de rendement : 6 kg/m²
- Surface totale : 10 hectares
- Demande d'évapotranspiration totale de la culture : 980 mm/m² par an
- Précipitations annuelles moyennes : 625 mm
- Coefficient de pertes de pluie (ruissellement, fuite, interception): 0,2
- Efficacité de l'irrigation : 0,3 (cas 1)
- Besoin en engrais : 0,012 kg/m² par an
- Concentration résiduelle : 8 mg/L



Source: Paolo Perona, CC-BY-SA

**Tâches :**

1) Calculez les empreintes bleue, verte et grise de l'eau pour le scénario actuel (efficience de l'irrigation = 0,3).

2) Déterminez comment ces empreintes changent si l'efficacité de l'irrigation est portée à 0,75.

# Example: water footprints for crop production

Étape 1 : Calculer le rendement total

Rendement total = Rendement par unité de surface × Surface totale

$$= 6\ \mathrm{kg/m^2} \times (10\ \mathrm{hectares} \times 10,000\ \mathrm{m^2/hectare})$$
$$= 6\ \mathrm{kg/m^2} \times 100,000\ \mathrm{m^2} = 600,000\ \mathrm{kg}$$

Étape 2 : Calculer l'empreinte hydrique verte

Empreinte verte de l'eau = demande des cultures satisfaite par les précipitations

Eau verte (provenant des précipitations) = (précipitations annuelles moyennes) × (1 - coefficient de perte pour les précipitations)

Pluie efficace = 625 mm × (1−0.2) = 500mm = 0.5m

Volume d'eau verte = Pluie effective × Surface = 0.5 m x 100000 $m^2$ = 50000 $m^3$

Empreinte hydrique verte par kg = Volume d'eau verte / Rendement total = **83.3 litres/kg**

# Example: water footprints for crop production

<u>Étape 3</u>. Calcul de l'empreinte eau bleue :

Eau d'irrigation nécessaire (eau bleue) = (demande d'évapotranspiration - précipitations effectives) / efficacité de l'irrigation = (980 mm – 500mm)/0.3 = 1600 mm

Volume d'eau bleue = eau d'irrigation nécessaire x surface irriguée = 1.6 m x 100000m$^2$= 160000 m$^3$

Empreinte hydrique bleue par kg = Volume d'eau bleue / rendement total = **267.7 litres/kg**

Avec une efficacité d'irrigation plus élevée = **106.7 litres/kg**

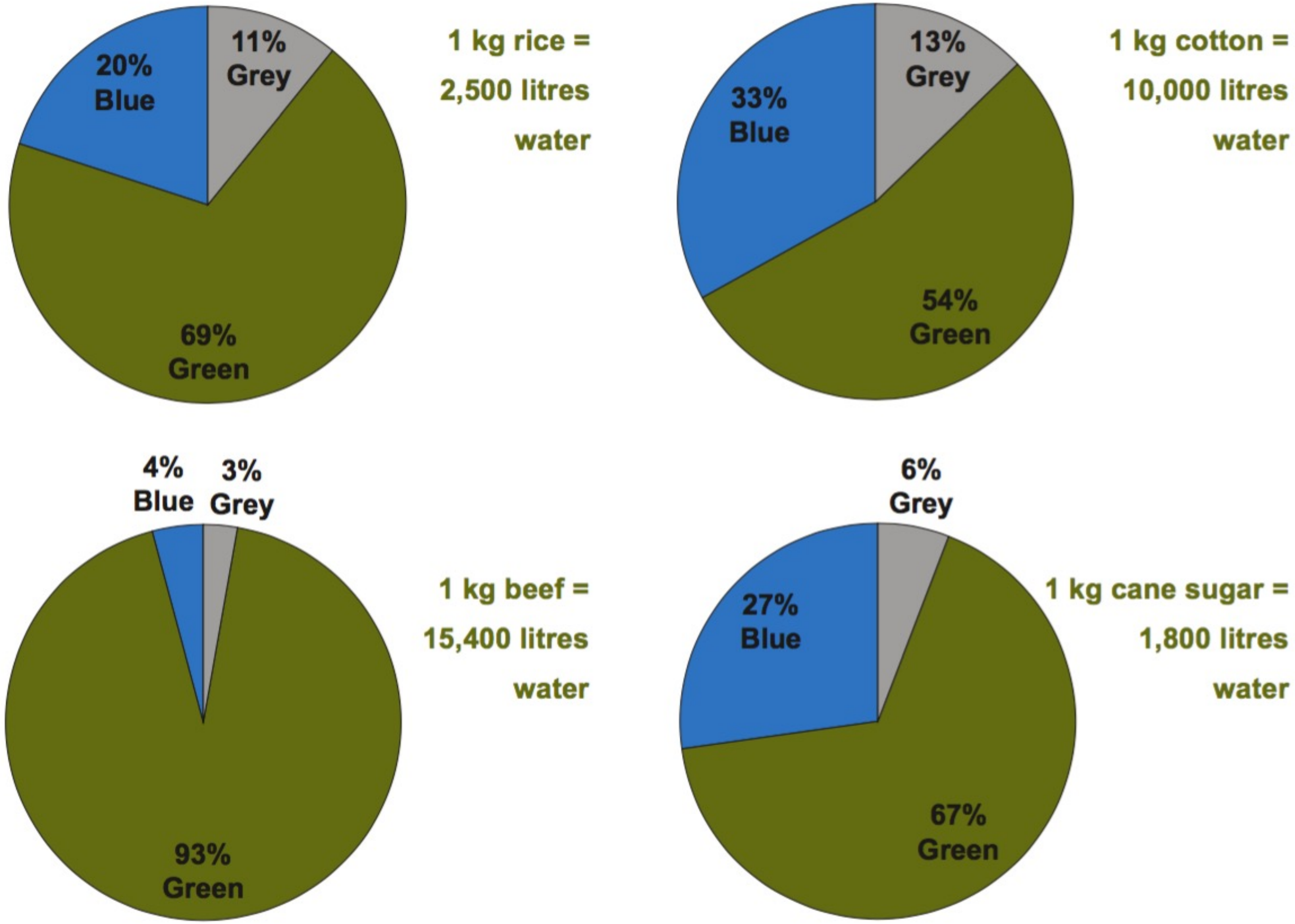
<u>Étape 4</u>. Calcul de l'empreinte eau grise

Charge d'azote = Taux d'application de l'engrais × Surface = 0.012 kg m$^{-2}$ x 100000 m$^2$ = 1200 kg

Volume d'eaux grises = Charge d'azote / (Concentration résiduelle) = 1200 kg /8 g m$^{-3}$ = 150000 m$^3$

Empreinte hydrique grise par kg = 150 10$^6$ litres / 600000 kg = **250 litres/kg**

# How much water do we need to produce our goods?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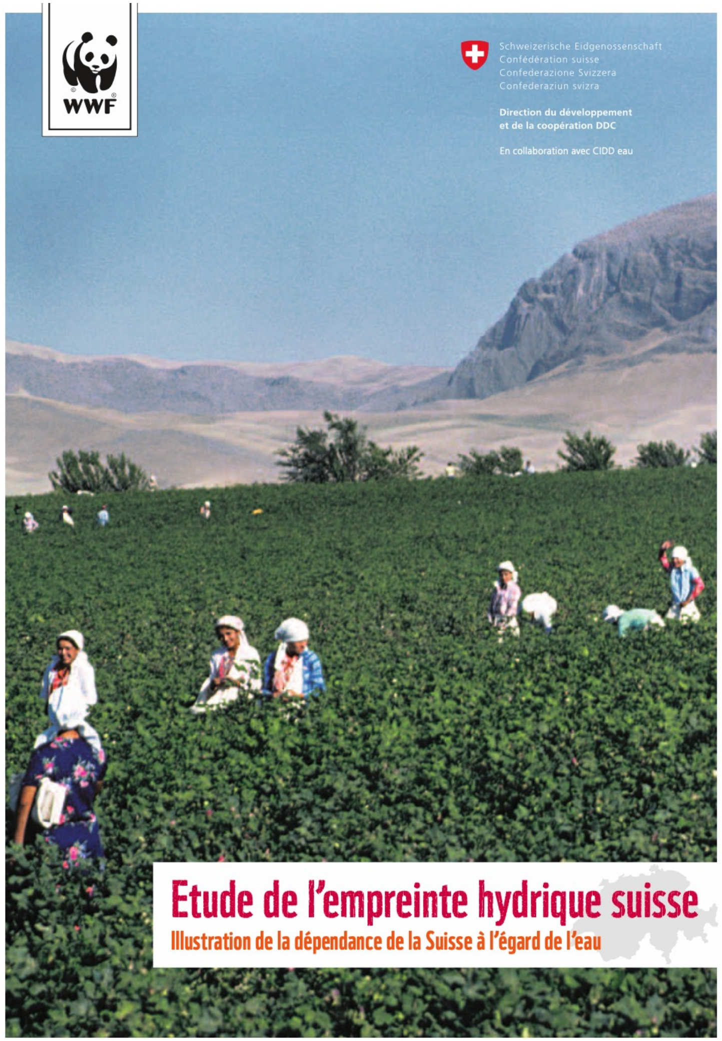
# Example: the Swiss case

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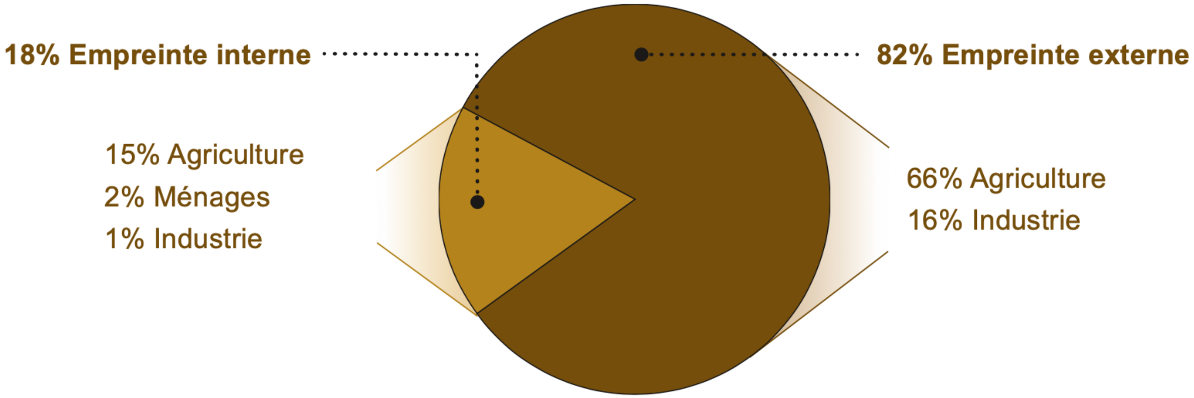
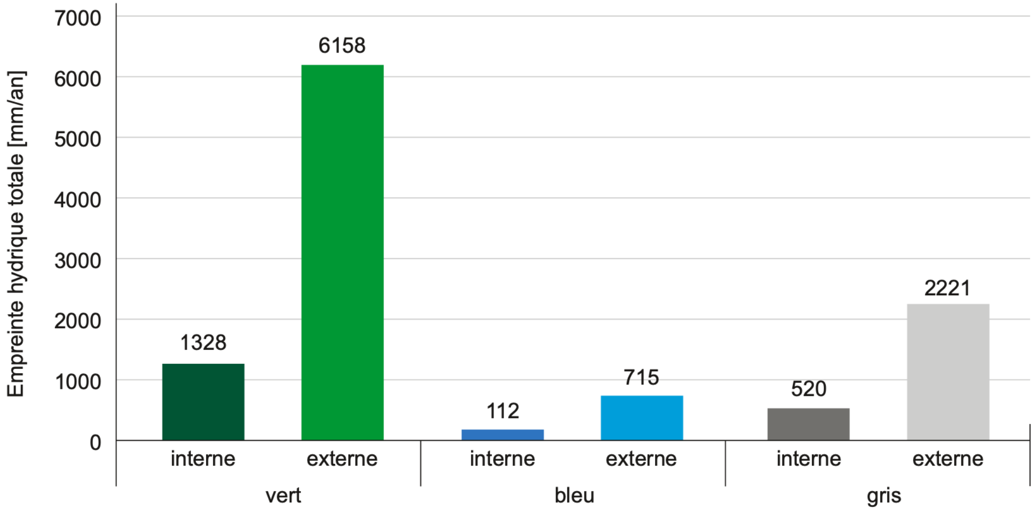



La Suisse, dont la part de l'empreinte hydrique interne n'atteint que **18%**, porte bien mal son nom de «château d'eau» de l'Europe. Une part impressionnante de la consommation d'eau (**82%**) de la Suisse est liée à des ressources hydriques extérieu



# Average national water footprint per capita



World average:

**1300 m³/cap/yr**

**3560 l/cap/day!**

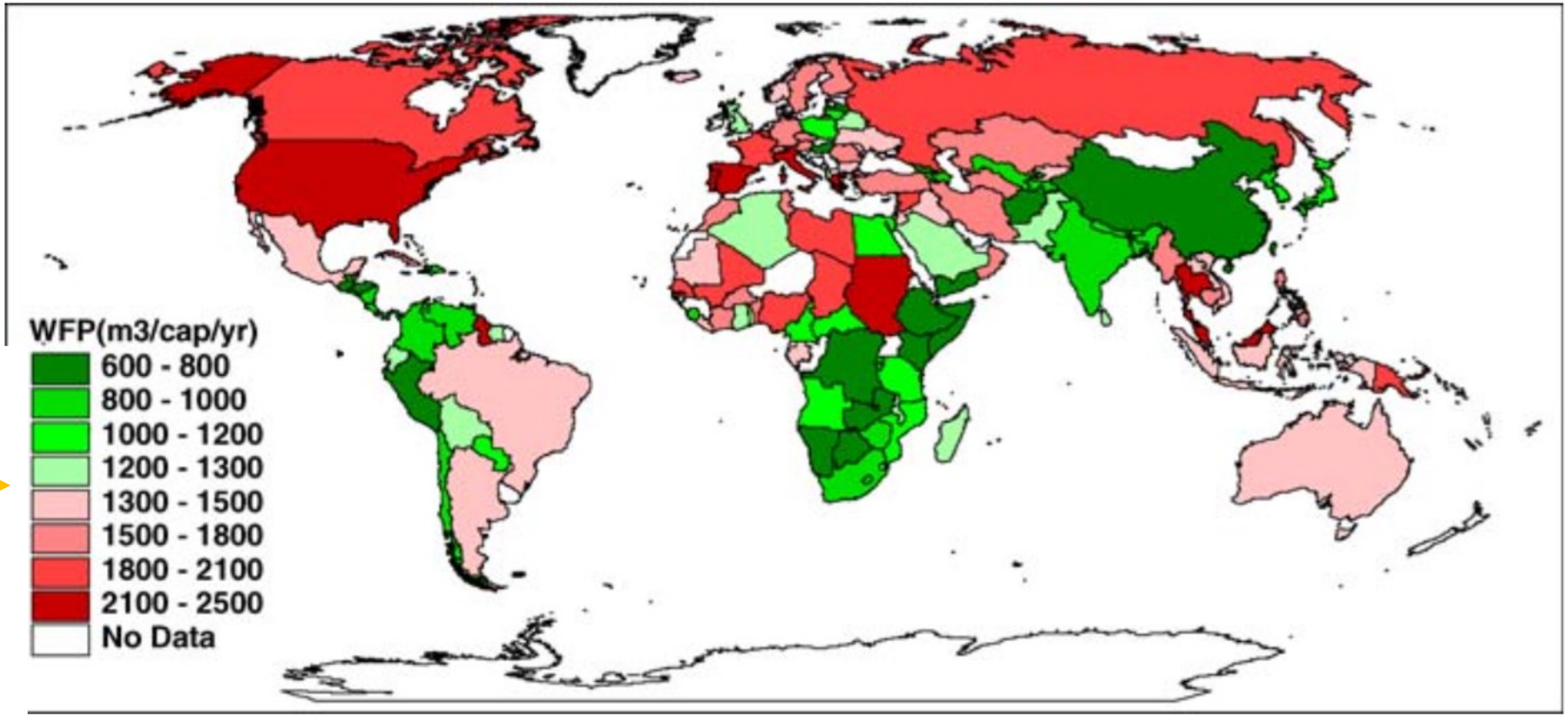



**Fig. 2** Average national water footprint per capita ($m^3$/capita/yr). Green means that the nation's water footprint is equal to or smaller than global average. Countries with red have a water footprint beyond the global average

# Virtual (or phantom) water and related network



"Water footprint of a cup of black coffee: 140 liters: This includes the water used for growing the coffee plant, harvesting, refining, transporting and packaging the coffee beans, selling the coffee, and brewing the final cup."

CHAPAGAIN, A.K. AND HOEKSTRA, A.Y., 2007

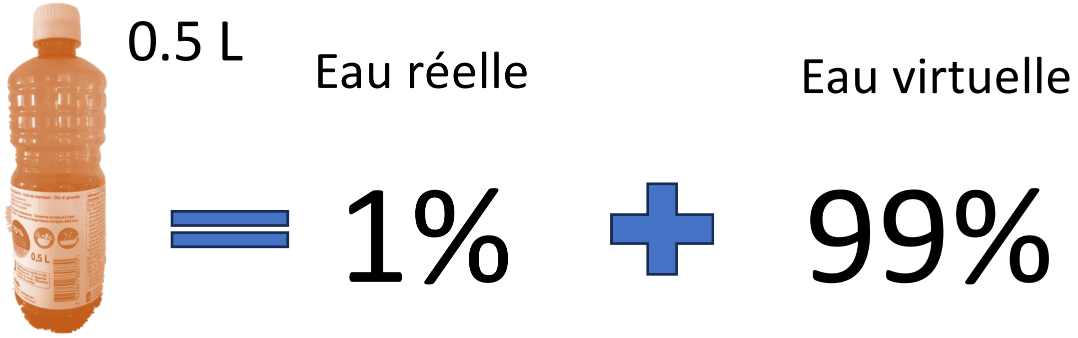
What is virtual water and does it tell us in terms of water footprint and international dependences?

# Link between virtual water and water footprint

Virtual water (also known as integrated water or phantom water) reflects the fact that the quantity of water physically contained in the product is negligible compared to the quantity used to produce it.

The concept of virtual water allows for precise and practical applications, since the quantities of water used in production processes can be quantified.

A country's water footprint is the volume of water resulting from direct use (e.g. consumption) and indirect use (e.g. the production of goods and services consumed by its inhabitants), plus the volume used to produce imported goods.

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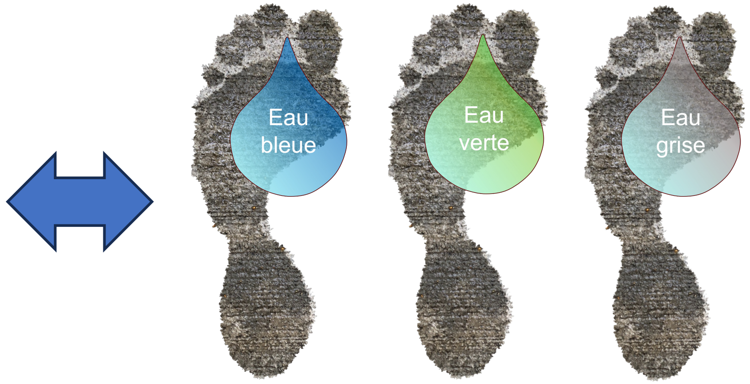
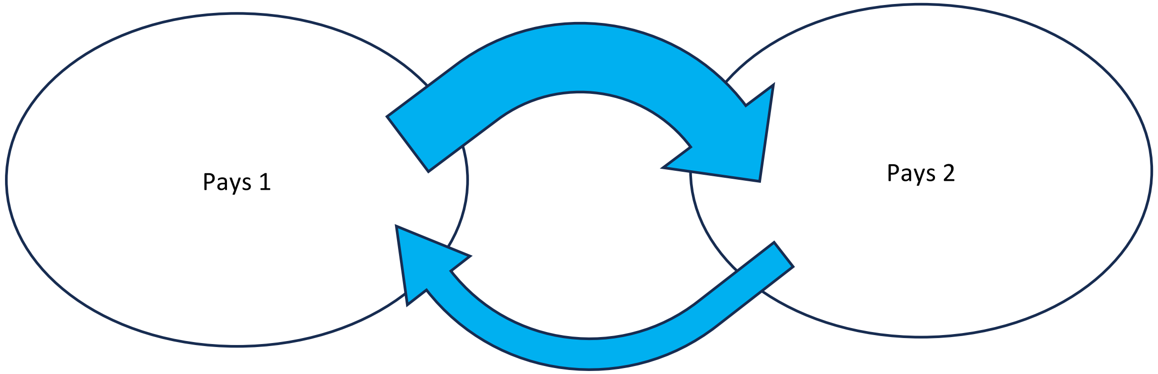
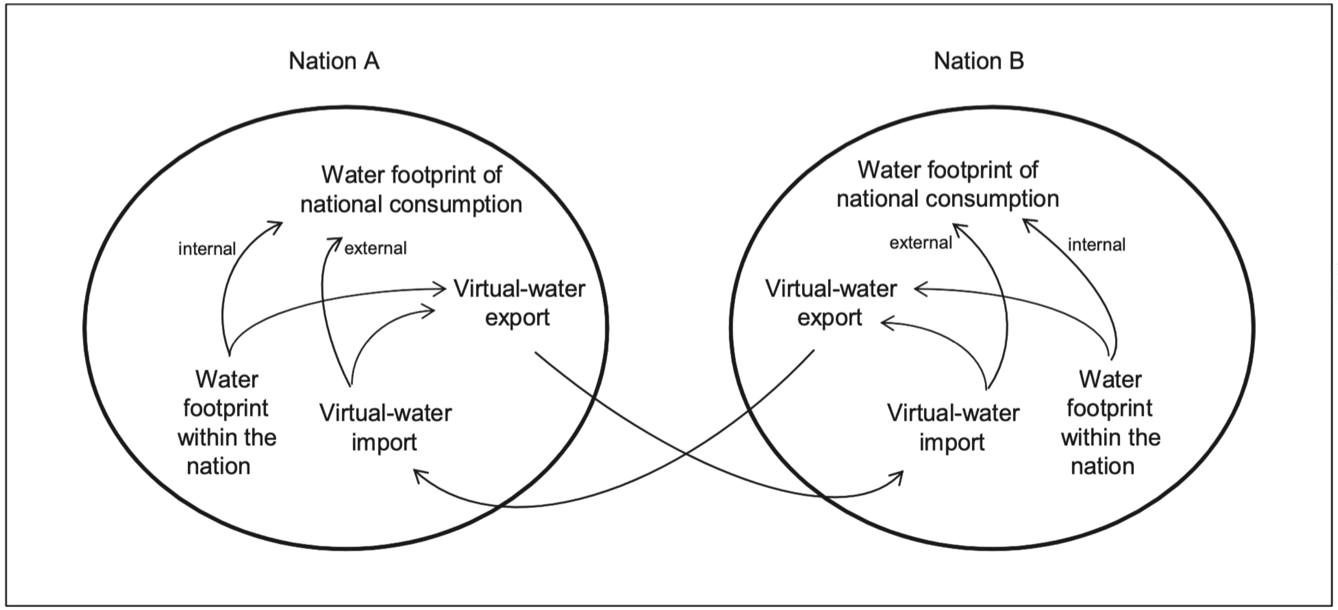
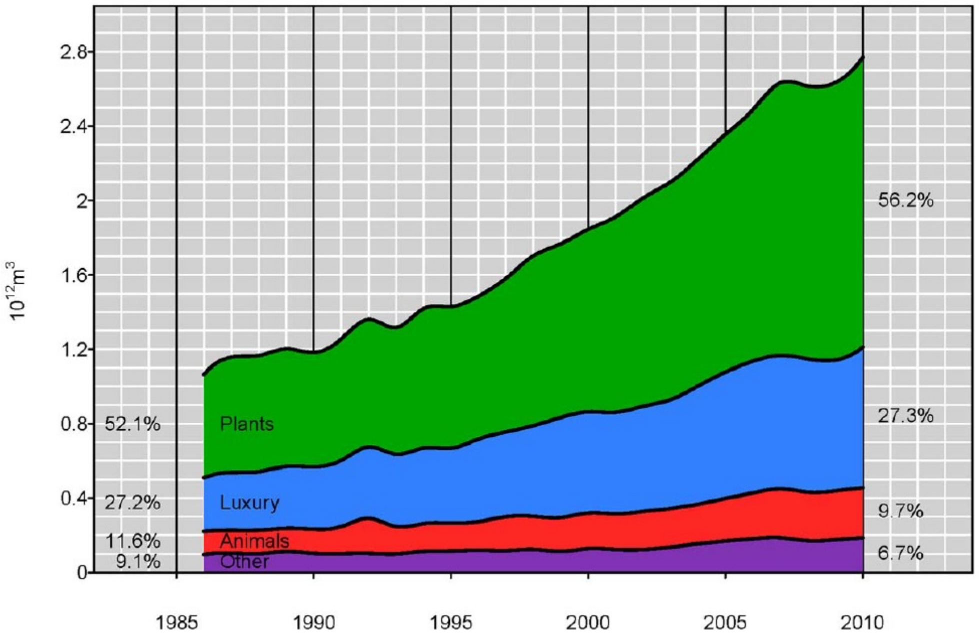


# Virtual water network



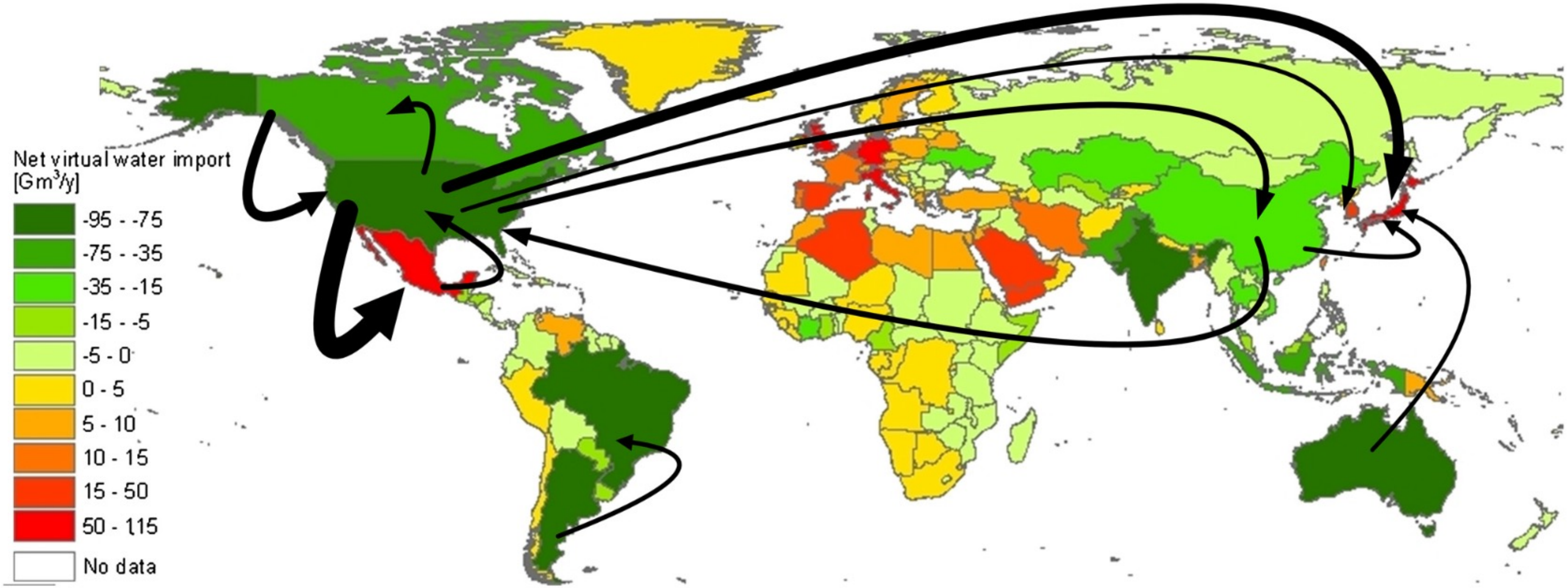




Carr et al., PloSOne, 2013

Net = Total virtual import – Total virtual export

Hoekstra et al., WFP assessment Manual, 2011

# Net virtual water export and import countries



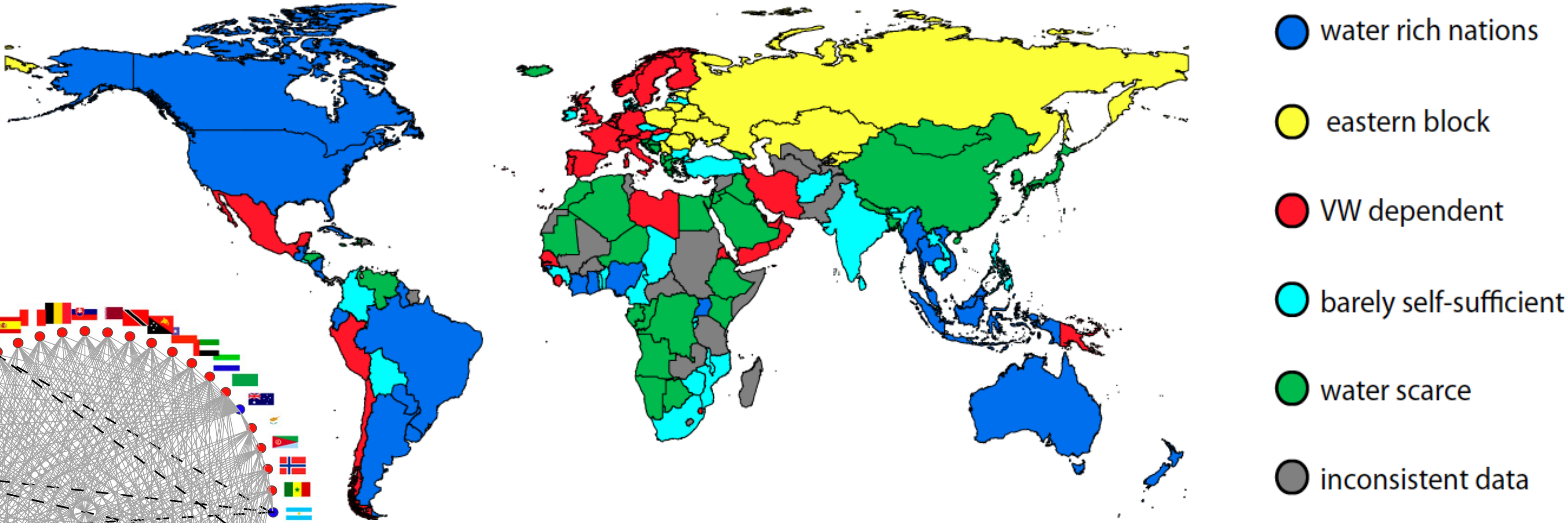

Basic idea: transferring goods means virtually transferring the water needed to produce them.

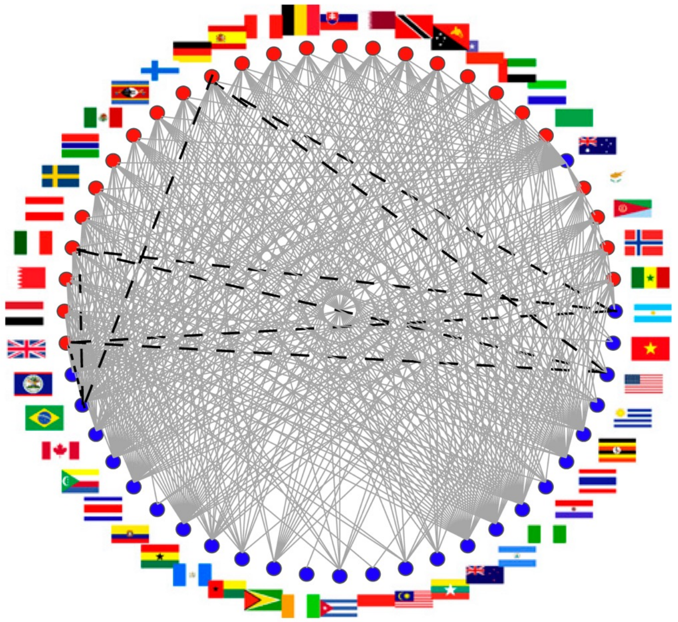
Green countries: net exporters
Yellow/red: net importers

Source: Hoekstra and Mekonnen, 2012

# International dependencies





Almost all of Europe is dependent on virtual water, and therefore economically dependent on non-European countries.

(*after Suweis et al., PNAS 2013,* Konar et al., WRR, 2010; Suweis et al., GRL, 2011)

# Challenges and solution for a sustainable management

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Sustainable management of freshwater is essential to guarantee access to drinking water for current and future generations.

| Questions (local → global) | Défi | Solution possibles |
|---|---|---|
| Pénurie d'eau | Faire face à la croissance démographique et au niveau d'urbanisation | Mesures de conservation de l'eau (agriculture, pratiques d'irrigation, pratiques de recyclage de l'eau) |
| Pollution de l'eau | Ruissellement industriel et agricole, traitement inadéquat | Appliquer une réglementation stricte, améliorer la technologie |
| Dégradation des écosystèmes | Altération des cours d'eau naturels, des habitats, perte de biodiversité | Gestion intégrale, restauration, débits dynamiques |
| Impacts du changement climatique | Modifications des précipitations, intensification. Extrêmes (par exemple, inondations, sécheresses), | Gestion résiliente au climat, infrastructures adaptatives, agriculture économe en eau |
| Concurrence intersectorielle | Exigences contradictoires entre l'agriculture, l'habitat et les utilisations industrielles | Allocation équitable, technologies permettant d'économiser l'eau, collaboration intersectorielle |
| Gouvernance | Faible gouvernance, réglementation inadéquate, manque de coordination | Renforcer les politiques de coopération, améliorer l'engagement des parties prenantes |