WATER RESOURCES : A WORLD GRAND CHALLENGE

Vince Bralts

Professor, Agricultural and Biological Engineering

ABE 290 Sophomore Seminar

Fall 2016

WATER QUOTES

"When the well is dry we learn the worth of water."

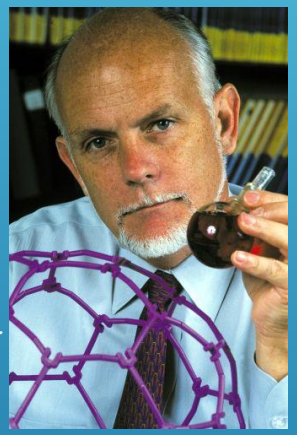
Benjamin Franklin, Poor Richard's Almanac

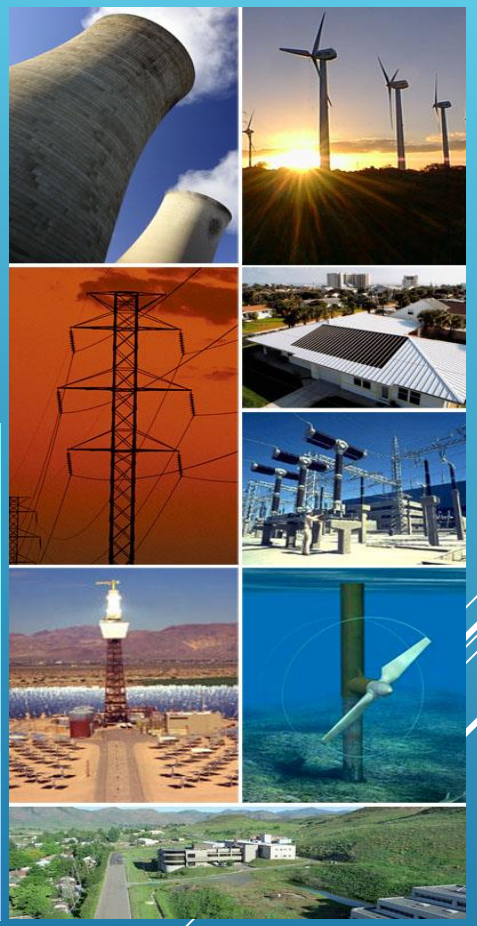
"***Water mingles with every kind of natural phenomenon; and more than one might imagine, it has also mingled with the particular destiny of mankind***"

Fernand Braudel

NOBEL LAUREATE RICHARD SMALLEY

- The World's Grand Challenges …
  - Energy
  - Water
  - Food
  - Environment
  - Poverty
  - Terrorism & War
  - Disease
  - Education
  - Democracy
  - Population





WATER RESOURCES TRIVIA

- How many liters of water does it take to produce one kilogram of grain?

- *How many liters of water are required to produce one kg of beef?*

- How many liters of water does it take to produce one liter of ethanol?

WATER RESOURCES TRIVIA

- How many liters of water does it take to produce one kilogram of grain?

  Answer : 1,000 liters

- *How many liters of water are required to produce one kg of beef?*

- How many liters of water does it take to produce one liter of ethanol?

WATER RESOURCES TRIVIA

- How many liters of water does it take to produce one kilogram of grain?

Answer : 1,000 liters

- *How many liters of water are required to produce one kg of beef?*

Answer : 15,000 liters

- How many liters of water does it take to produce one liter of ethanol?

WATER RESOURCES TRIVIA

- How many liters of water does it take to produce one kilogram of grain?

Answer : 1,000 liters

- *How many liters of water are required to produce one kg of beef?*

Answer : 15,000 liters

- How many liters of water does it take to produce one liter of ethanol?

Answer : 3000 liters

OTHER WATER RESOURCES TRIVIA

- *1 Apple requires 68 liters of water*
- *1 slice of bread requires 41 liters of water to produce*
- *1 Glass of beer requires 75 liters of water to produce*
- *1 kg of chicken requires 3,900 liters of water to produce*
- *1 Cotton shirt 2,700 liters of water to produce*
- *1 round of golf requires 9,000 liters water*

Source : FORTUNE October 12,2009 (World Resources Institute).

WATER TECHNOLOGY AND SOCIETY ISSUES

- Hydrologic Cycle
- Availability of Water
- Ground Water Resources
- Stored Water Resources
- Agriculture and Water
- Water and Food Security
- Irrigated Crops and land Use
- Soil Salinization and Waterlogging
- Economic costs of Water
- Water in Livestock Production
- Water and Human Health
- Effects of Climate Change
- Conflicts over Water Use
- Water Conservation

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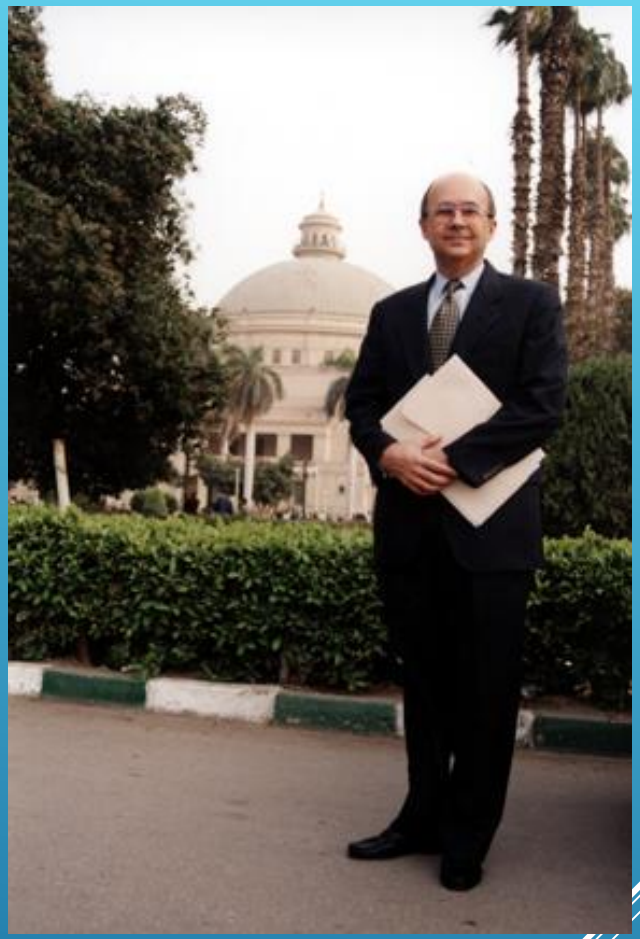
"If the wars of this century were fought over oil, the wars of the next century will be fought over water"

August 1995



ISMAIL SERAGELDIN

FORMER VP WORLD BANK

http://www.serageldin.com/gallery.aspx

- International Watercourses (1997)

"***Article 5, contained in Part II, reflects the principle that is widely regarded as the cornerstone of the Convention, and indeed the law in the field: equitable and reasonable utilization and participation. It requires that a State sharing an international watercourse with other States utilize the watercourse, in its territory, in a manner that is equitable and reasonable vis-à-vis the other States sharing it. In order to ensure that their utilization of an international watercourse is equitable and reasonable, States are to take into account all relevant factors and circumstances". - S.C. McCaffrey***

"Another key provision of the Convention is article 7 (Obligation not to cause significant harm). This article requires that States "take all appropriate measures to prevent the causing of significant harm" to other States sharing an international watercourse." - S.C.McCaffrey

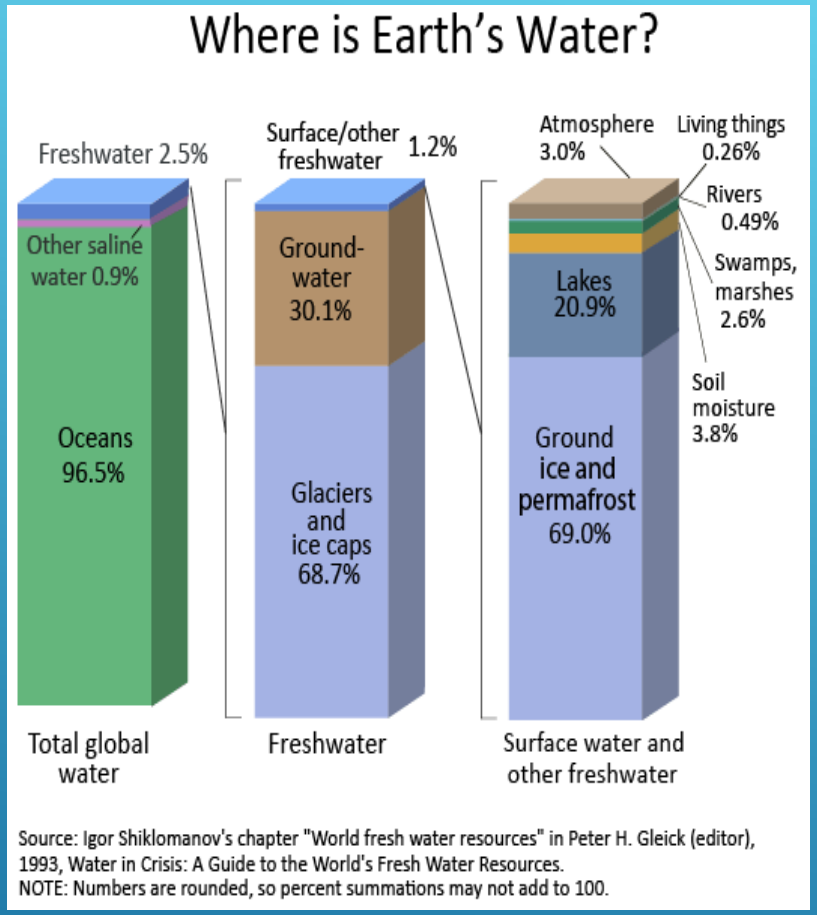
http://www.un.org/waterforlifedecade/transboundary_waters.shtml

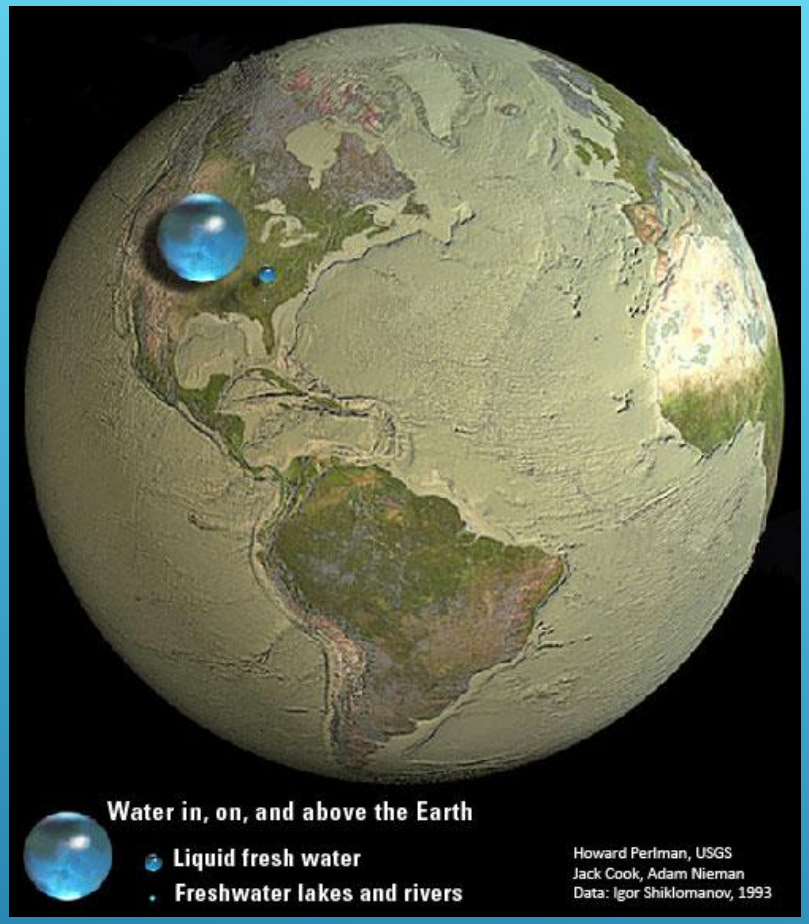
http://legal.un.org/avl/pdf/ha/clnuiw/clnuiw_e.pdf

UN RESOLUTION : GENERAL ASSEMBLY RESOLUTION 51/229

GLOBAL OVERVIEW

While 67% of Earth's surface is covered by water, only less than 2.7% of global water is freshwater. Most of the freshwater (2.05%) is locked in ice caps and glaciers. Only less than 0.7% is available for human use.





WORLDS FRESH WATER RESOURCES

http://water.usgs.gov/edu/
http://water.usgs.gov/edu/earthwherewater.htm

VOLUME OF WATER STORED IN THE WATER CYCLE'S RESERVOIRS

Reservoir	Volume of water (10^6 km^3)	Percent of total
Ocean	1370	97.25
Ice caps & glaciers	29	2.05
Groundwater	9.5	0.68
Lakes	0.125	0.01
Soil Moisture	0.065	0.005
Atmosphere	0.013	0.001
Streams & rivers	0.0017	0.0001
Biosphere	0.0006	0.00004

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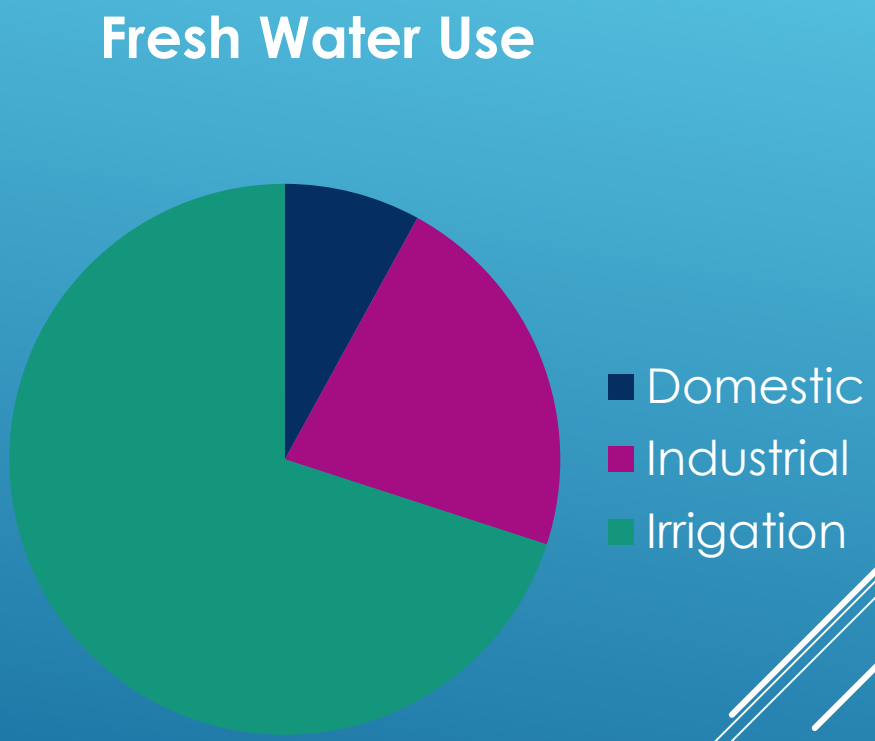
GREENLAND'S ICE SHEET

WORLDWIDE

- Domestic 8%
- Industry 22%
- Irrigation 70%



Source : FORTUNE October 12,2009 (World Resources Institute).

Water and Food Security

Water scarcity is one of the most pressing global challenges. Approximately 2.8 billion people – more than 40% of the world's populations - are affected by water scarcity. As more than 70% of the world's water is used in agriculture, global food security is particularly hampered by the lack of available water.

- http://securingwaterforfood.org/

USAID AND SWEDEN LAUNCH WATER GRAND CHALLENGE FOR DEVELOPMENT

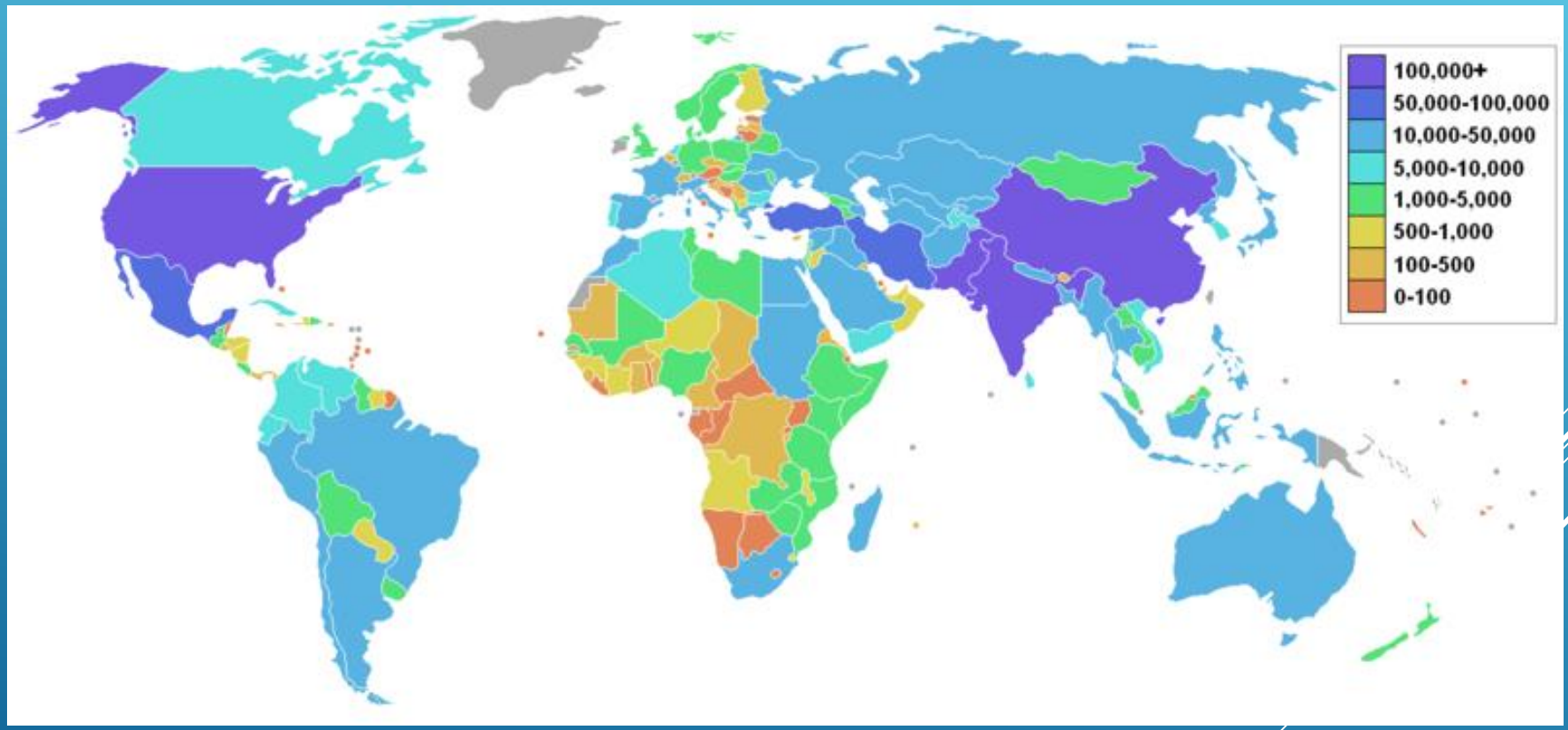
USAID Press Release September 2, 2013

SANDRA POSTEL

- **"Water use tripled between 1950 and 1990**
  - as world population soared by some 2.7 billion…
- **Worldwide demand for water cannot triple again**
  - without causing severe shortages for
    - **crop irrigation,**
    - **industrial use,**
    - **basic household needs and**
    - **critical life-supporting ecosystems"**

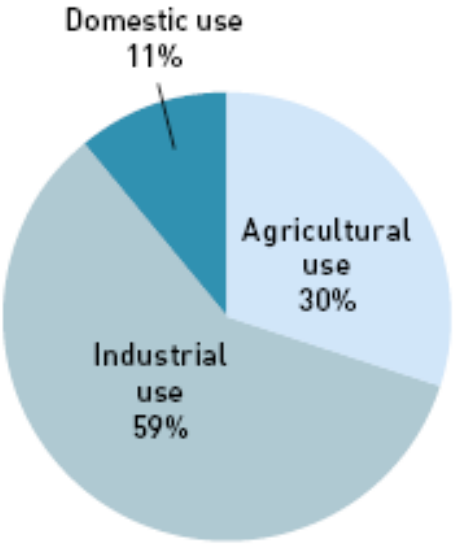
http://www.hipco-ne.com/imaghttp://www.globalwaterpolicy.org/images/sandrapostel1_19.jpg
http://www.hipco-ne.com/images/gated.gif

IRRIGATED LAND

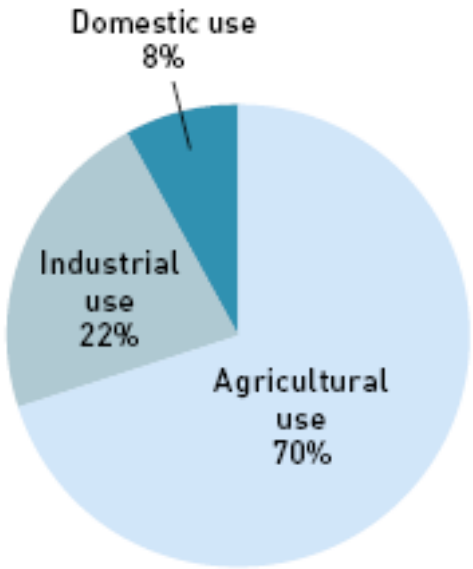


upload.wikimedia.org/wikipedia/commons/4/4a/Irrigated_land_world_map.png

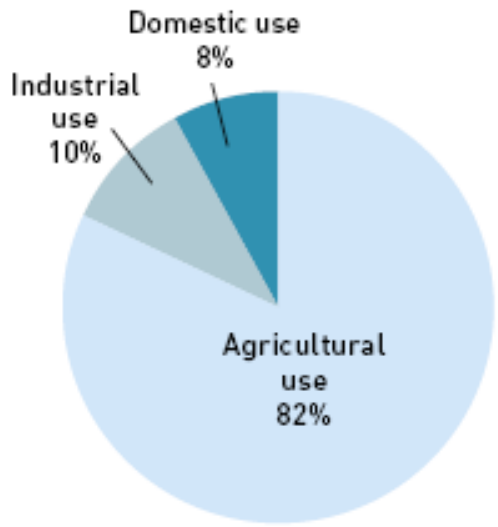
COMPETING WATER USES



Competing water uses
(high-income countries)

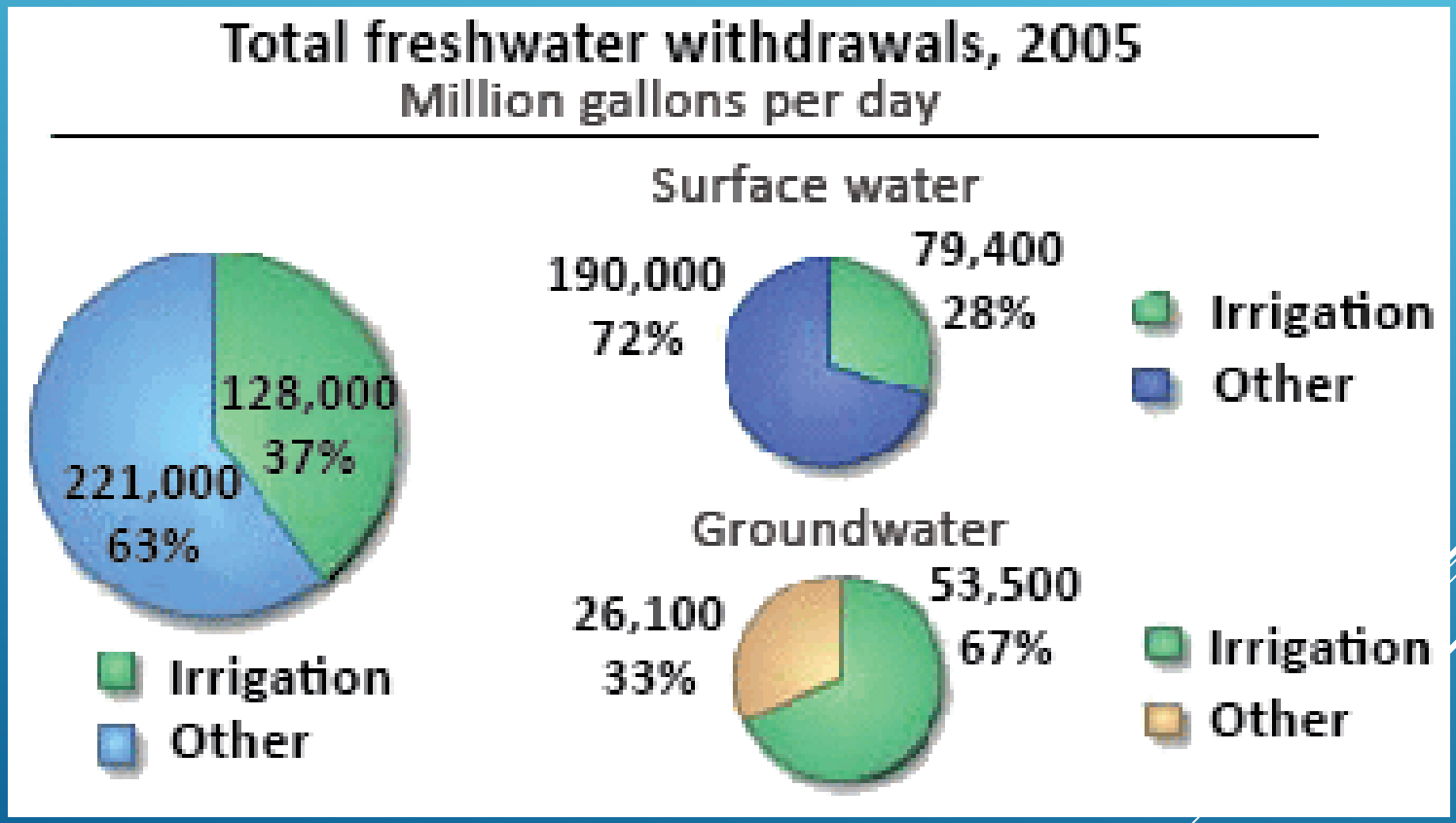


Competing water uses
(world)

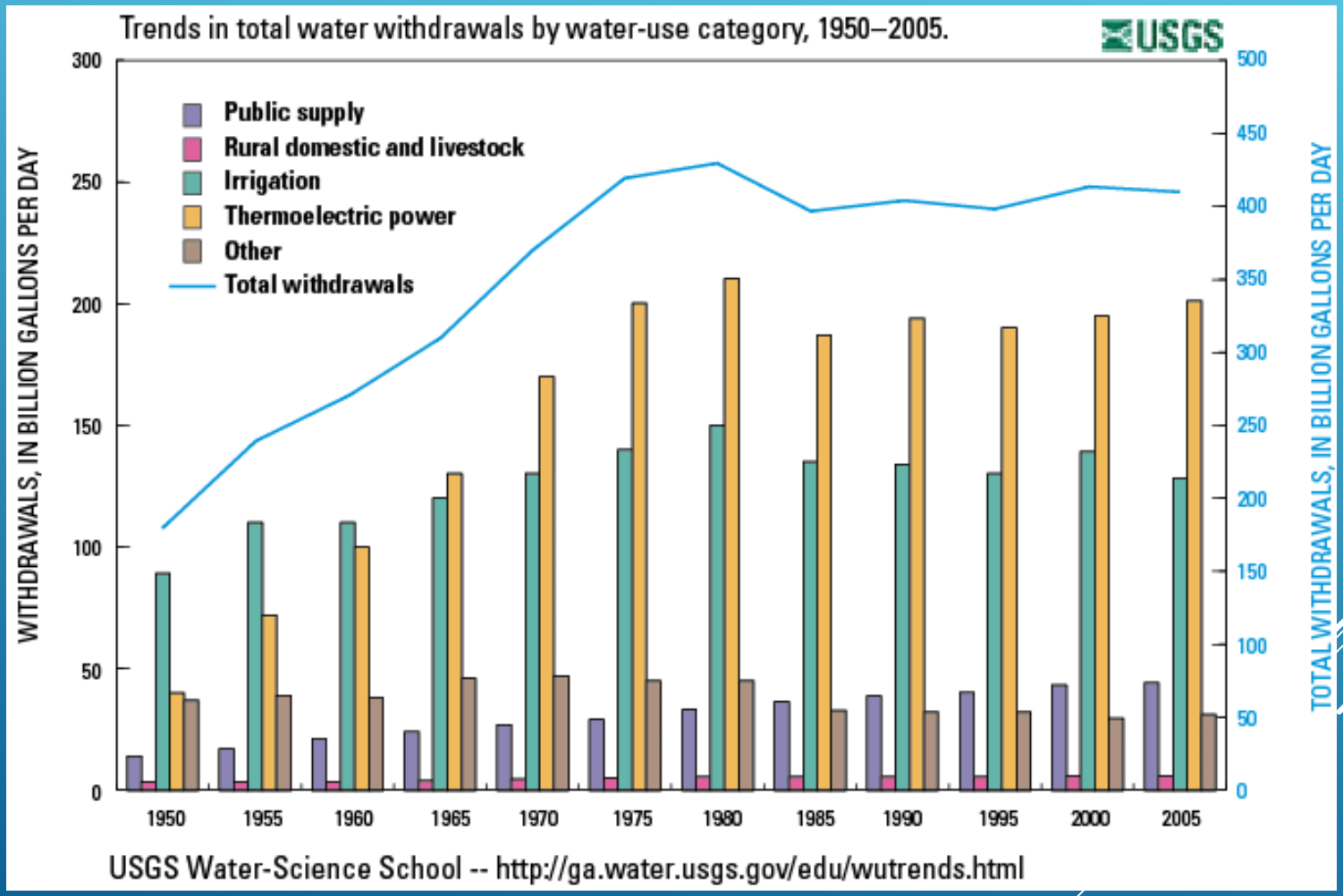


Competing water uses
(low- and middle-income
countries)

FRESH WATER WITHDRAWALS FOR THE USA, 2005



US WATER WITHDRAWALS



WHAT IS THE "**WATER FOOTPRINT**" OF

- A PRODUCT ?
- AN INDIVIDUAL ?
- A NATION?

Water Footprint

DR. ARJEN HOEKSTRA

MSC CIVIL ENGINEERING, PHD POLICY ANALYSIS
PROF. WATER MANAGEMENT AT UNIVERSITY OF TWENTE, THE NETHERLANDS

Creator:

"The Water Footprint"

2002

Established the interdisciplinary field of Water Footprint Assessment (WFA) and the Water Footprint Network

Water Footprint

http://www.bdforum.org/baltic-sea-award-waterfootprint/

A Comprehensive Introduction to Water Footprints

Professor in Water Management – University of Twente – the Netherlands

Scientific Director – Water Footprint Network

Many of the subsequent Slides were taken from Hoekstra 2011

[Hoekstra & Chapagain, 2008]

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National water footprint accounting

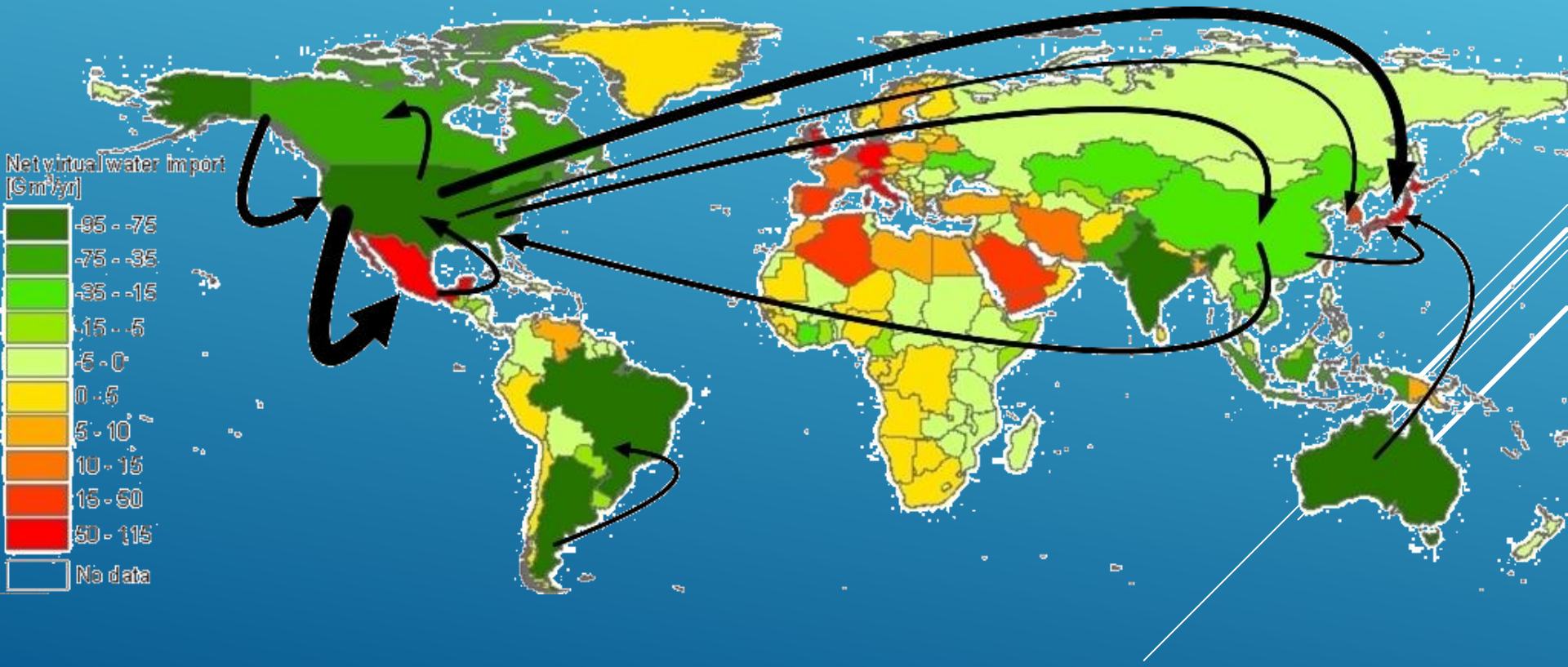
A PRODUCT'S **WATER FOOTPRINT** IS…

the VOLUME of freshwater used in the entire chain of production

http://www.bwt-group.com/en/water-technology/the-element-h20/Pages/Virtual-water.aspx

A PRODUCT'S **WATER FOOTPRINT** IS…

dependent on WHERE and WHEN is was produced



http://www.waterfootprint.org/WFP_files/Img/InternationalVirtualWaterFlo

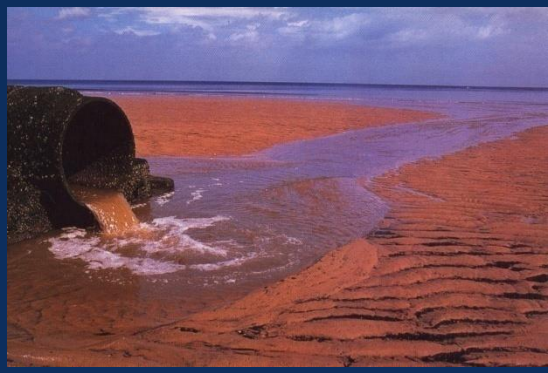
The water footprint of a product

Green water footprint

► volume of rainwater evaporated or incorporated into product.

Blue water footprint

► volume of surface or groundwater evaporated, incorporated into product or returned to other catchment or the sea.



Grey water footprint

► volume of polluted water.

Hoekstra 2011

Evapo-transpiration of rainwater stored in the soil as moisture, including rainwater incorporated in the crop.

Surface or ground water evaporated or incorporated into a product, e.g. agriculture irrigation.

The volume of freshwater needed to dilute pollution to agreed quality standards, e.g. industrial water pollutants and fertiliser residuals.

In addition to these definitions, we used a 'net green' approach, defined as the difference between rainwater used by the cultivated crop and by natural vegetation. Our calculation of the green water footprint has shown that (potential) natural vegetation consumes more water than sugar beet, so we set the 'net green' water footprint to zero.

Malin Falkenmark, Swedish hydrologist

Blue and green process water footprint:

Growing a crop:

Water footprint of growing a crop =

$$\frac{\text{Crop water use } (m^3/ha)}{\text{Crop yield (ton/ha)}}$$

Blue and green process water footprint:

Growing a crop:

Crop water use (CWU)=

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green}$$

+

$$CWU_{blue} = 10 \times \sum_{d=1}^{lgp} ET_{blue}$$

Green water evapotranspiration (ET) =
min (crop water requirement, effective precipitation)

Blue water evapotranspiration (ET) =
min (irrigation requirement, effective irrigation)

Malin Falkenmark, Swedish hydrologist

Blue and green process water footprint:
Growing a crop

Crop water requirement=

1. **Calculate reference crop evapotranspiration ET_0 (mm/day)**
   e.g. Penman-Monteith equation

2. **Calculate crop evapotranspiration Et_c (mm/day)**
   $Et_c = ET_0 \times K_c$ where K_c = crop coefficient

3. **Calculate crop water requirement *CWR* (m^3/ha)**
   $CWR = \Sigma\ Et_c$ [accumulate over growing period]

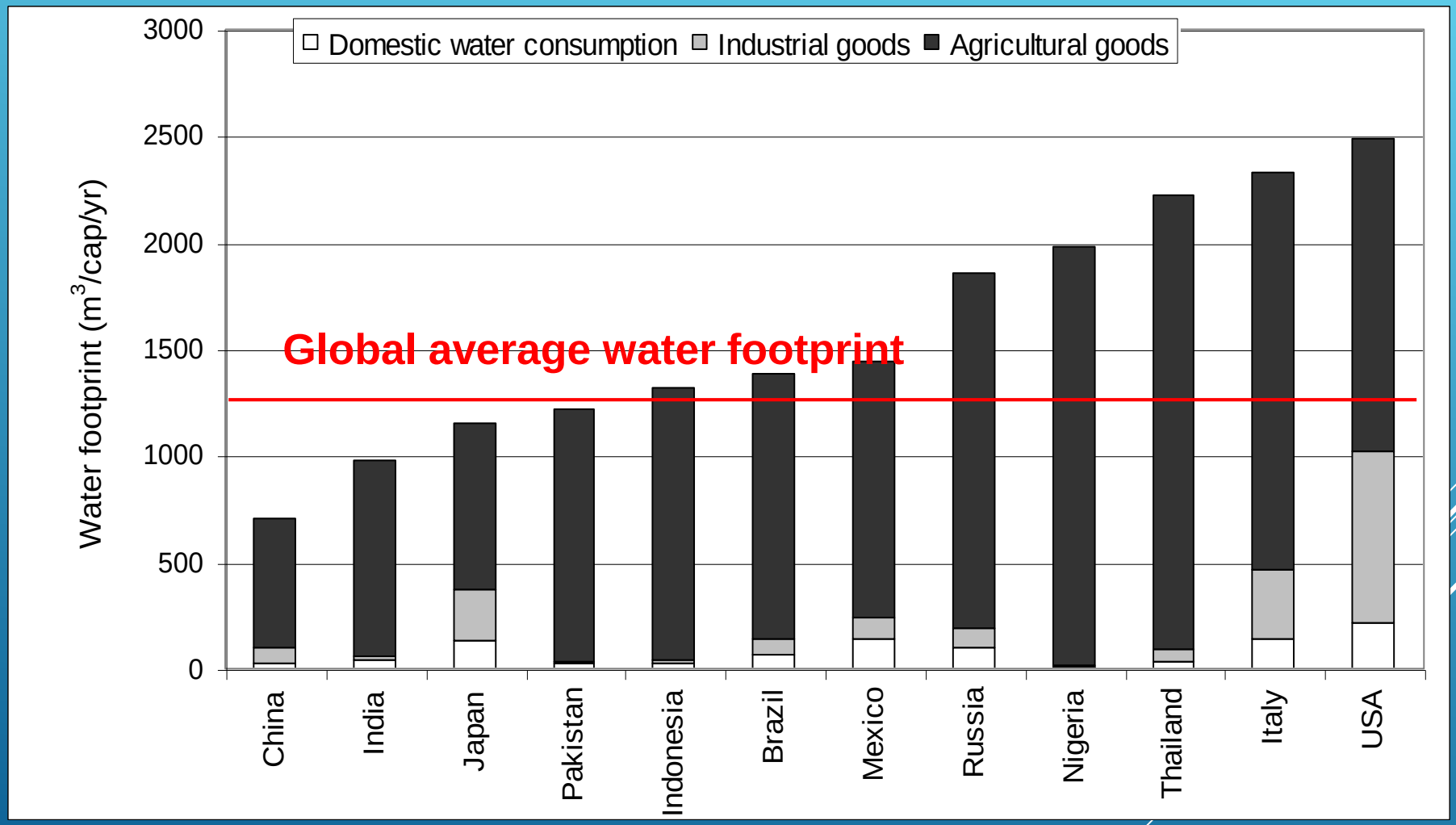
Blue and green process water footprint:

Growing a crop:

Irrigation requirement =

crop water requirement – effective rainfall

Water footprint of a Nation (per capita)



[Hoekstra & Chapagain, 2008]

D I R E C T

http://www.theguardian.com/business/gallery/2010/sep/16/1

http://www.lonelyplanet.com/guadeloupe/images/countryside-sugar-cane-fields-guadeloupe$925-16

I N D I R E C T

D I R E C T

http://www.theguardian.com/business/gallery/2010/sep/16/1

Component	Green (L)	Blue (L)	Grey (L)	Total (L)
Water as an ingredient	0	0.5	0	0.5
Consumption or pollution related to manufacturing process	0	0	0	0
Overhead activities of bottling facility (toilets, kitchen, etc.)	0	0	0	0

INDIRECT

Sugar
CO_2
Phosphoric or citric acid
Caffeine
Vanilla extract
Lemon oil
Orange oil

Tray carton (paperboard)
Tray shrink film (PE)
Pallet shrink wrap (PE)
Pallet label (coated paper)
Pallet (painted wood)

Closure (HDPE)
Bottle (PET)
Label (PP)

Concrete
Steel
Paper
Natural gas
Electricity
Vehicles
Fuel

Water Footprint of Coca Cola

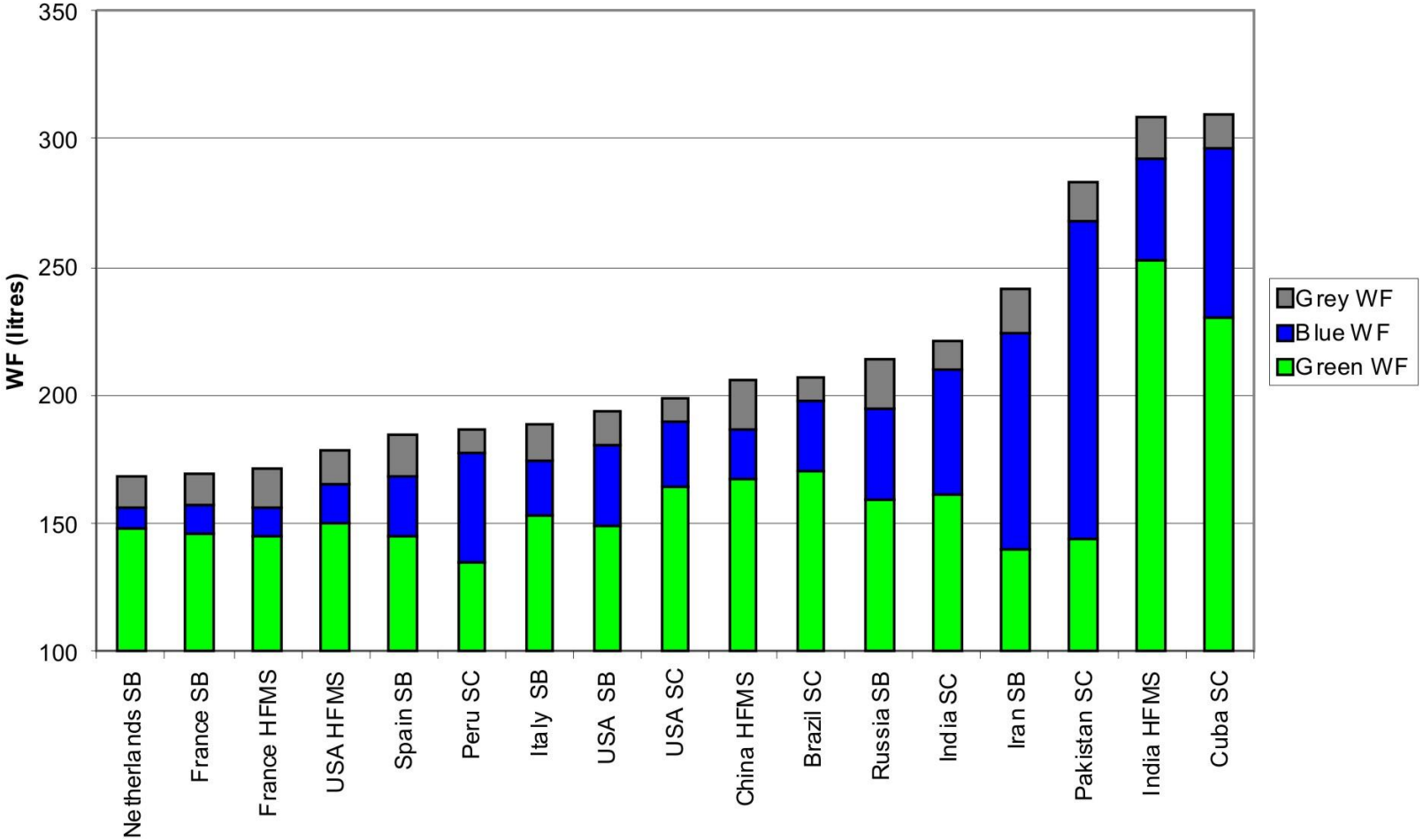
Indirect

Table 2 Water footprint of the ingredients of the sugar-containing carbonated beverage

Item	Raw material	Selected location	Water footprint of raw material (m^3/ton)			Process water requirement (m^3/ton)			Fractions for products used	
			Green	Blue	Grey	Green	Blue	Grey	Product fraction	Value fraction
Sugar	Sugar beet	Iran	21	298	36	0	0	0	0.16	0.89
Sugar	Sugar beet	Russia	89	123	16	0	0	0	0.16	0.89
Sugar	Sugar beet	USA	53	108	23	0	0	0	0.16	0.89
Sugar	Sugar beet	Italy	50	56	19	0	0	0	0.12	0.89
Sugar	Sugar beet	Spain	29	67	28	0	0	0	0.13	0.89
Sugar	Sugar beet	France	36	29	19	0	0	0	0.14	0.90
Sugar	Sugar beet	Netherlands	45	23	18	0	0	0	0.15	0.89
Sugar	Sugar cane	Cuba	310	214	20	0	0	0	0.14	0.86
Sugar	Sugar cane	Pakistan	29	402	26	0	0	0	0.14	0.86
Sugar	Sugar cane	Brazil	115	87	8	0	0	0	0.14	0.86
Sugar	Sugar cane	India	85	156	15	0	0	0	0.14	0.86
Sugar	Sugar cane	Peru	0	134	8	0	0	0	0.14	0.86
Sugar	Sugar cane	USA	95	79	10	0	0	0	0.14	0.86
Sugar	HFMS	India	1,163	376	100	0	0	0	0.36	0.73
Sugar	HFMS	USA	156	136	64	0	0	0	0.36	0.73
Sugar	HFMS	France	100	99	90	0	0	0	0.36	0.73
Sugar	HFMS	China	328	177	118	0	0	0	0.36	0.73
CO_2	Ammonia by product	USA	0	0	0	0	83.5[a]	0	1	1
Phosphoric acid	Phosphate rock	USA	0	0	0	0	0	0	1	1
Caffeine	Coffee beans	Colombia	14,470	0	0	0	0	0	0.0137	1
Vanilla extract	Vanilla	Madagascar	199,383	0	0	0	0	0	0.025[b]	1
Lemon oil	Lemon	World average	559	0	0	0	0	0	0.4	1
Orange oil	Orange	World average	457	0	0	0	0	0	0.0021	1

Water Footprint of soft drinks

Spatial and temporal dimension



http://www.waterfootprint.org/WFP_files/Img/VWF_Softdrinks.jpg

0.5 L vs 168.4 L

http://www.allianceforwaterefficiency.org/colorado-basin-study-released-2012.aspx

The total water footprint of a consumer in the UK

► about 3% of their water footprint is at home.

150 litre/day

► about 97% of their water footprint is ‘invisible’, it is related to the products you buy in the supermarket.

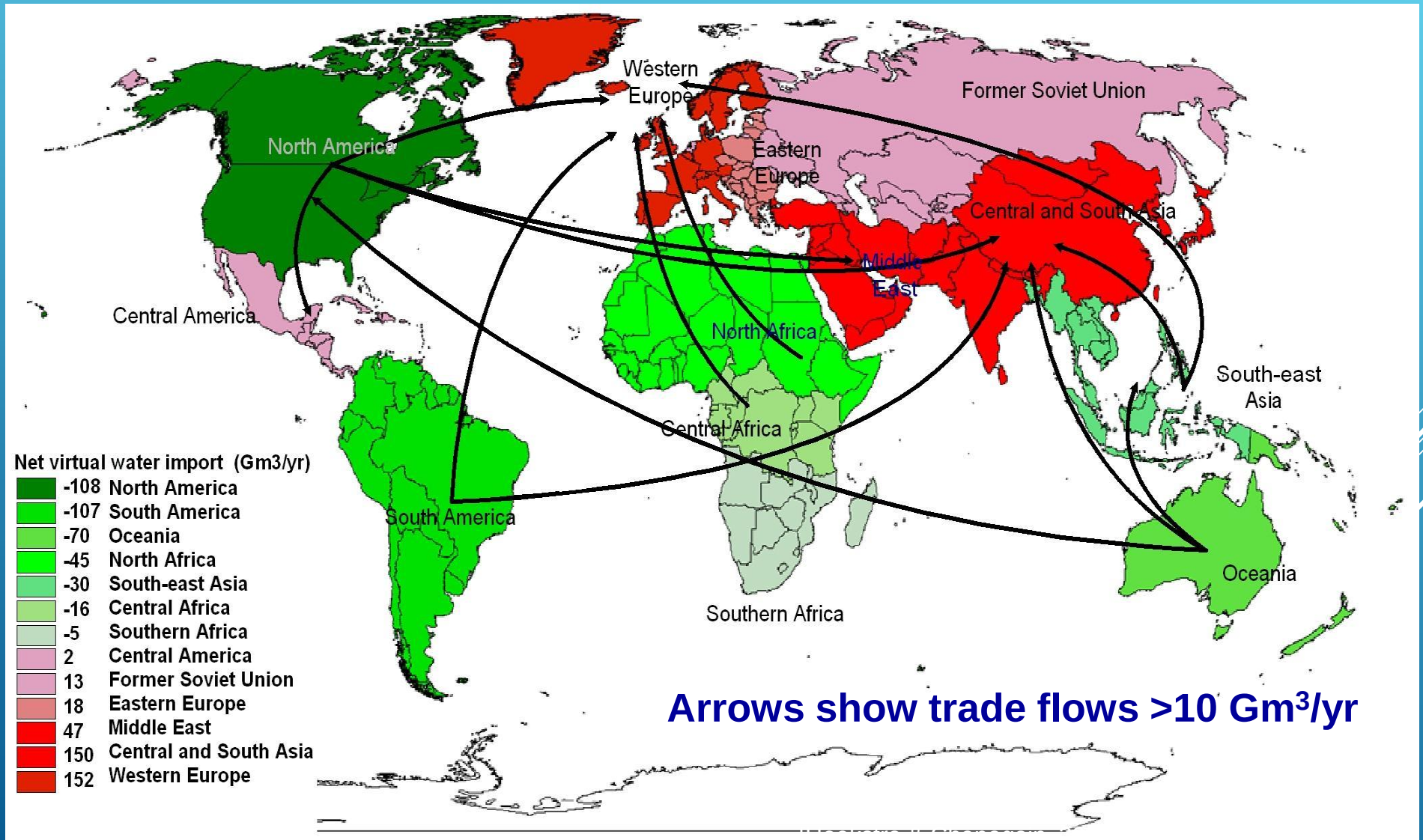
3400 litre/day for agricultural products
1100 litre/day for industrial products

► about 60 to 65% of your water footprint lies abroad.

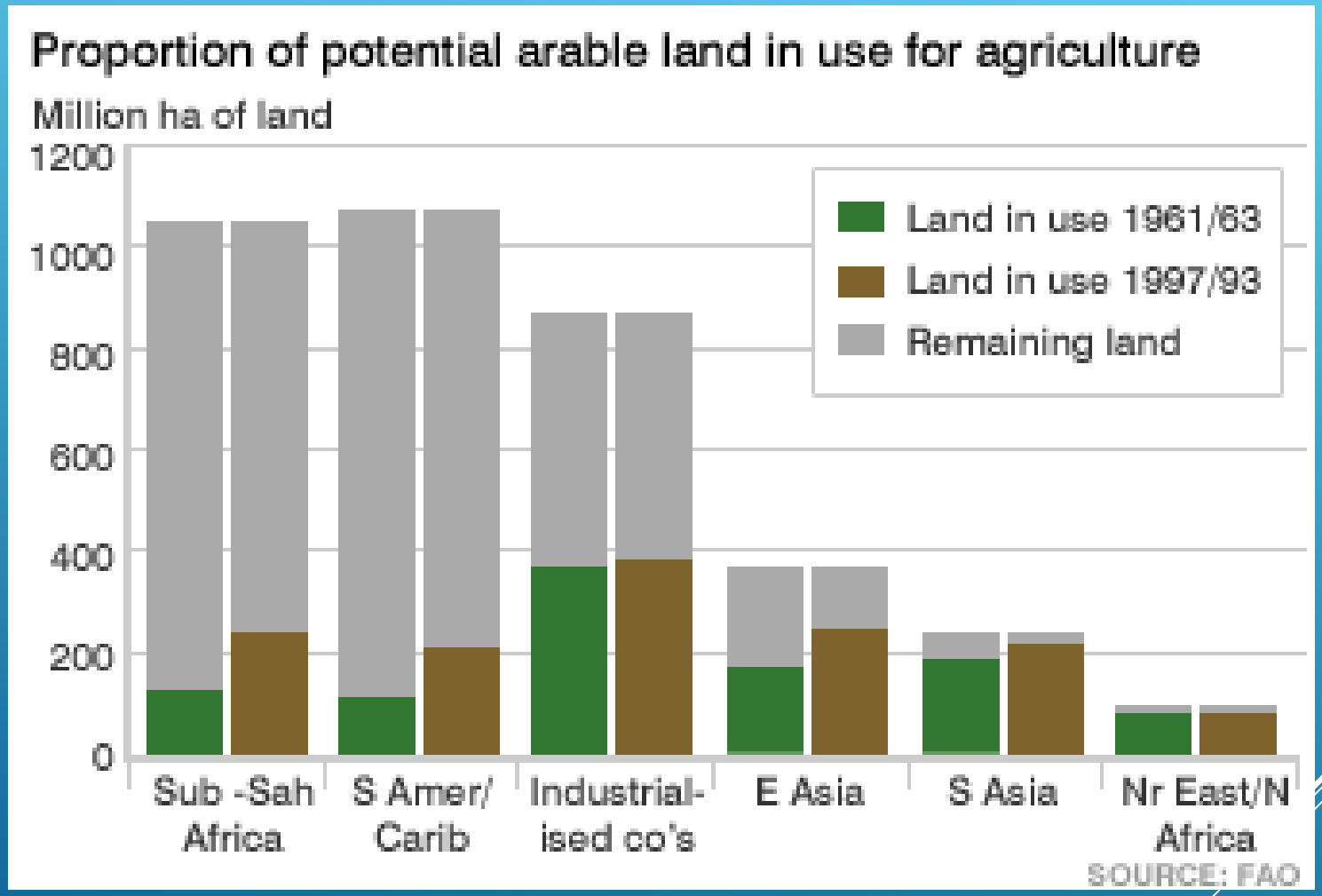
Meat versus vegetarian diet

	Meat diet	kcal/day	litre/kcal	litre/day	Vegetarian diet	kcal/day	litre/kcal	litre/day
Industrial countries	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
Developing countries	Animal origin	350	2.5	875	Animal origin	200	2.5	500
	Vegetable origin	2350	0.5	1175	Vegetable origin	2500	0.5	1250
	Total	2700		2050	Total	2700		1750

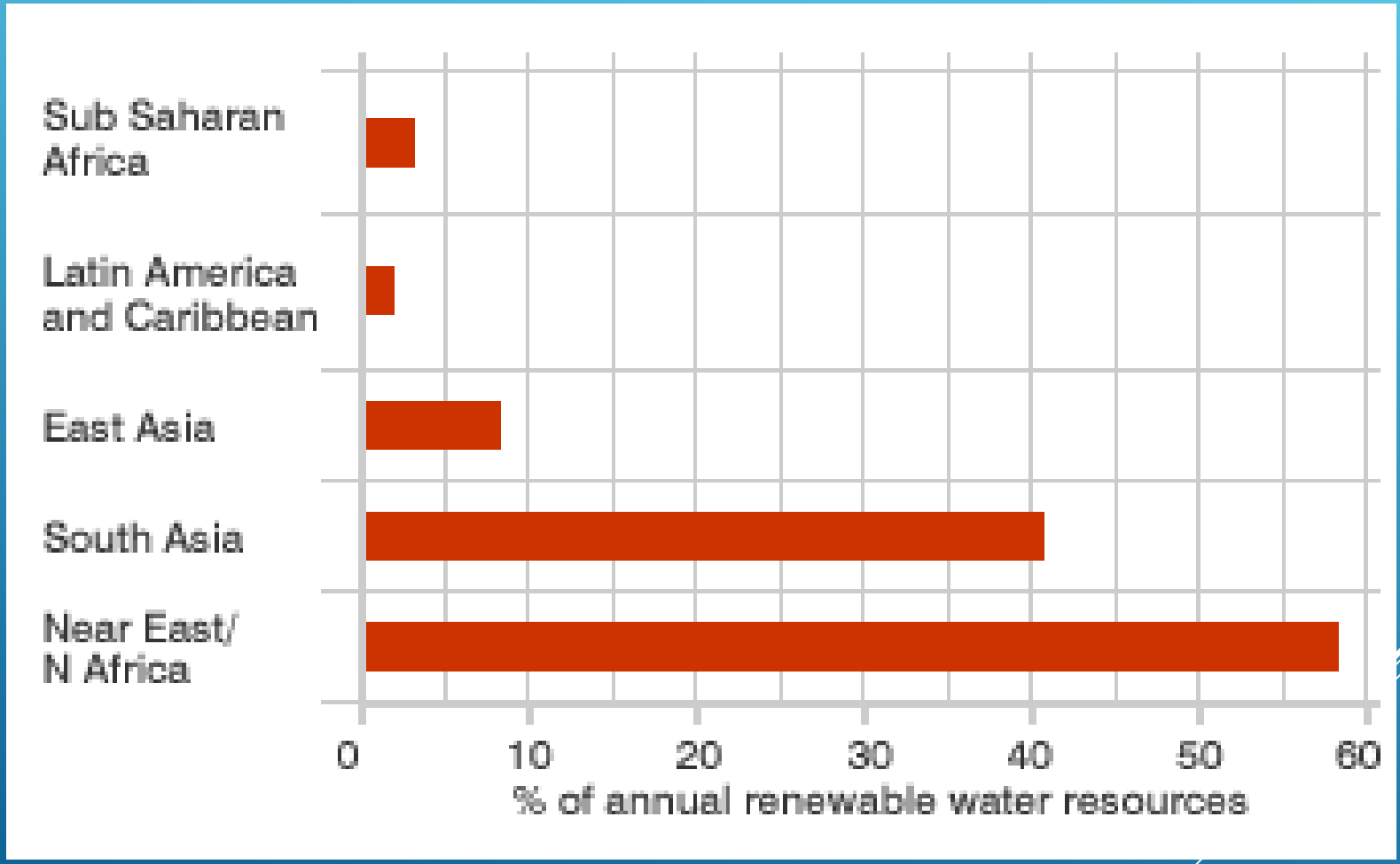
REGIONAL VIRTUAL WATER BALANCES
(ONLY AGRICULTURAL TRADE)



POTENTIAL ARABLE LAND



WATER WITHDRAWALS FOR IRRIGATION



GROUNDWATER IS . . .

- An important source of fresh water (represents over 90% of the world's readily available fresh water).
- Located in aquifers -- underground layers of porous rock and soil.
- Result of rain water seeping into the ground, eventually finding its way into aquifers.
- This underground water moves very slowly and may take a long time to recharge or refill.
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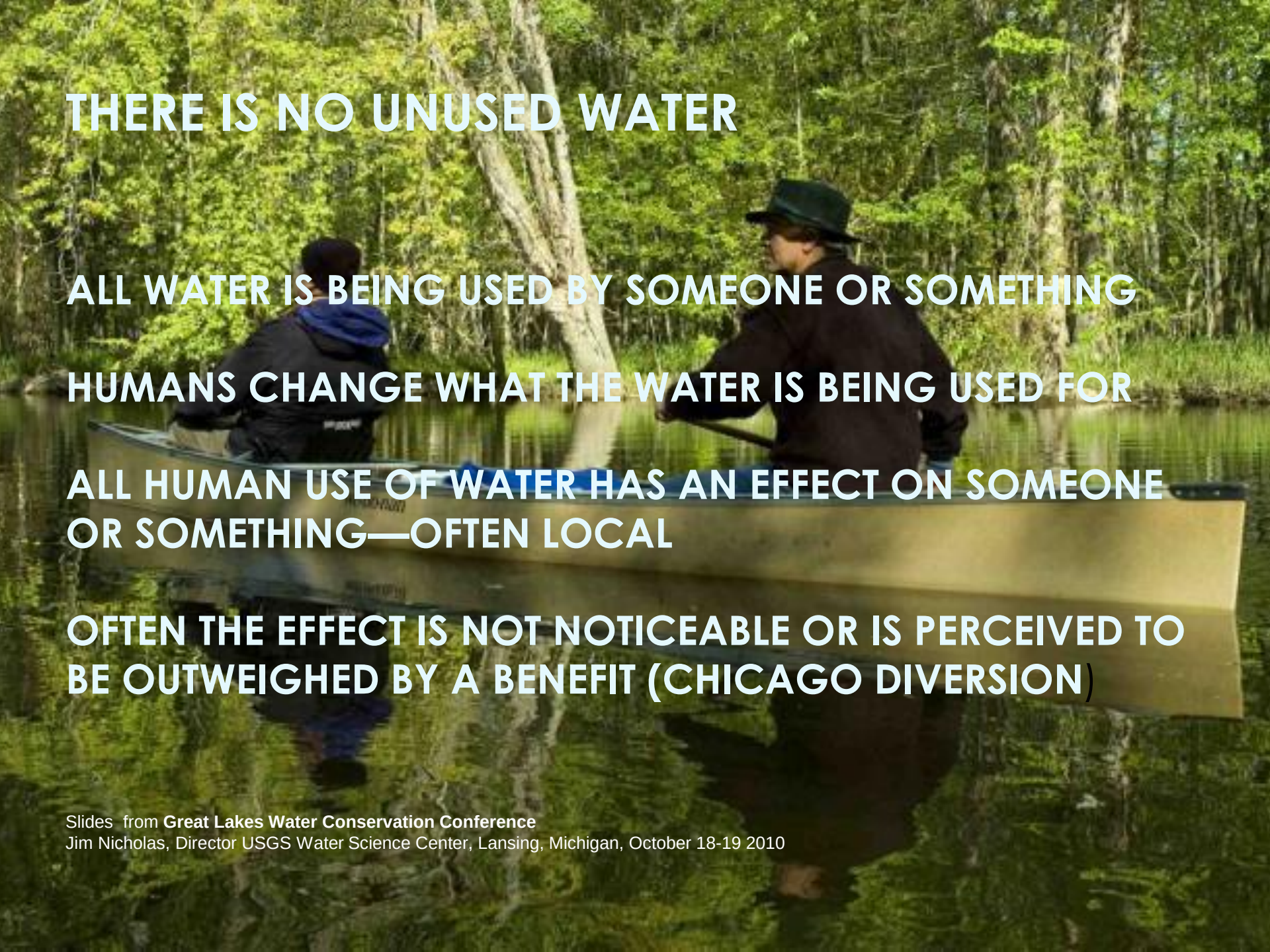
WATER SHORTAGES

- Between 1950 and 2000, world water use tripled
- Some 70% of water use is for irrigation
- Over extraction is leading to disappearing lakes and rivers failing to reach the sea
- Aquifer depletion is causing water tables to fall and wells to go dry
- 175 million Indians, 130 million Chinese are fed with grain produced by over pumping

Since the over pumping of aquifers is occurring in many countries more or less simultaneously, the depletion of aquifers and the resulting harvest cutbacks could come at roughly the same time, creating potentially unmanageable food scarcity.

Photo Credit: Yann Arthus-Bertrand



THERE IS NO UNUSED WATER

ALL WATER IS BEING USED BY SOMEONE OR SOMETHING

HUMANS CHANGE WHAT THE WATER IS BEING USED FOR

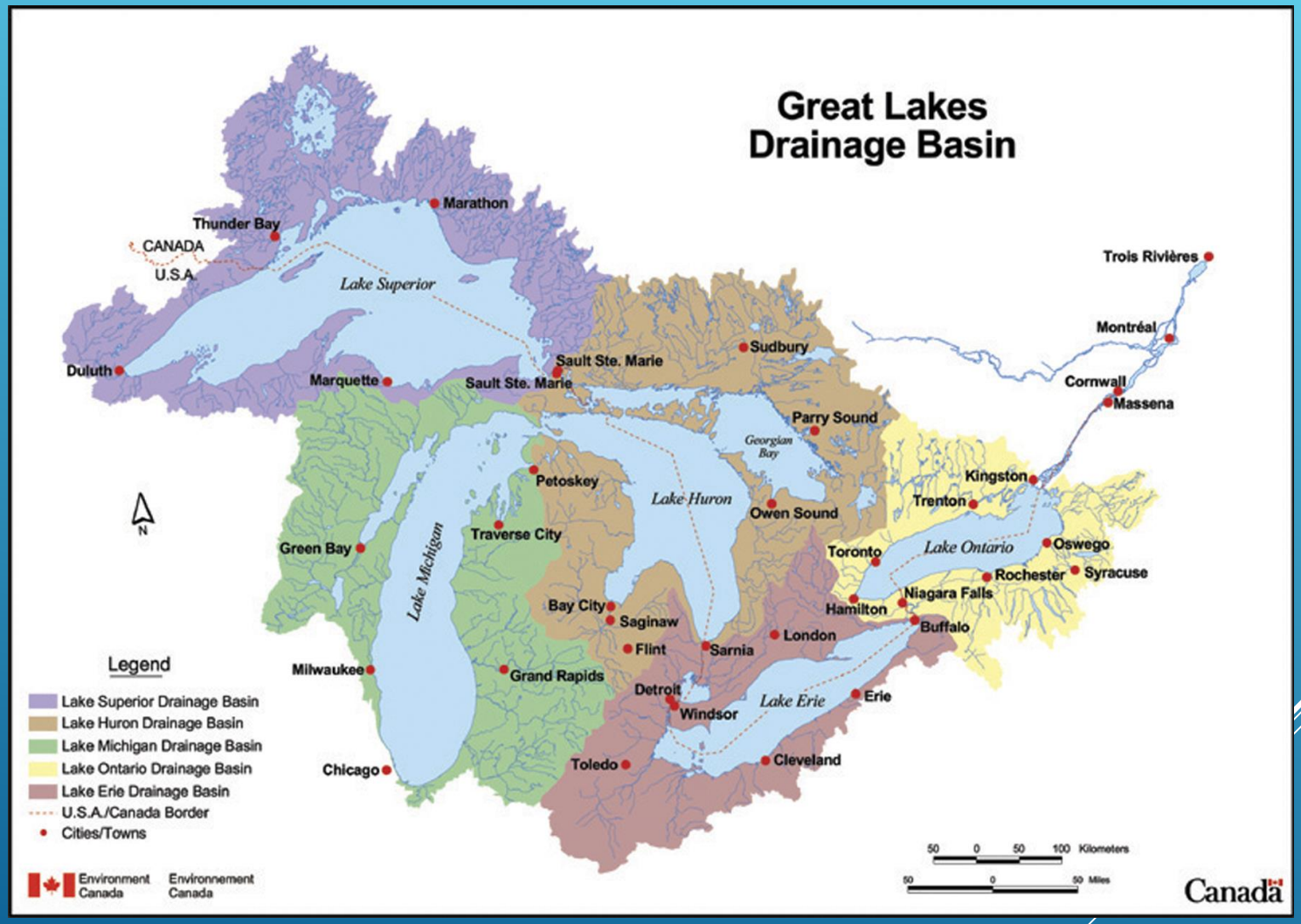
ALL HUMAN USE OF WATER HAS AN EFFECT ON SOMEONE OR SOMETHING—OFTEN LOCAL

OFTEN THE EFFECT IS NOT NOTICEABLE OR IS PERCEIVED TO BE OUTWEIGHED BY A BENEFIT (CHICAGO DIVERSION)

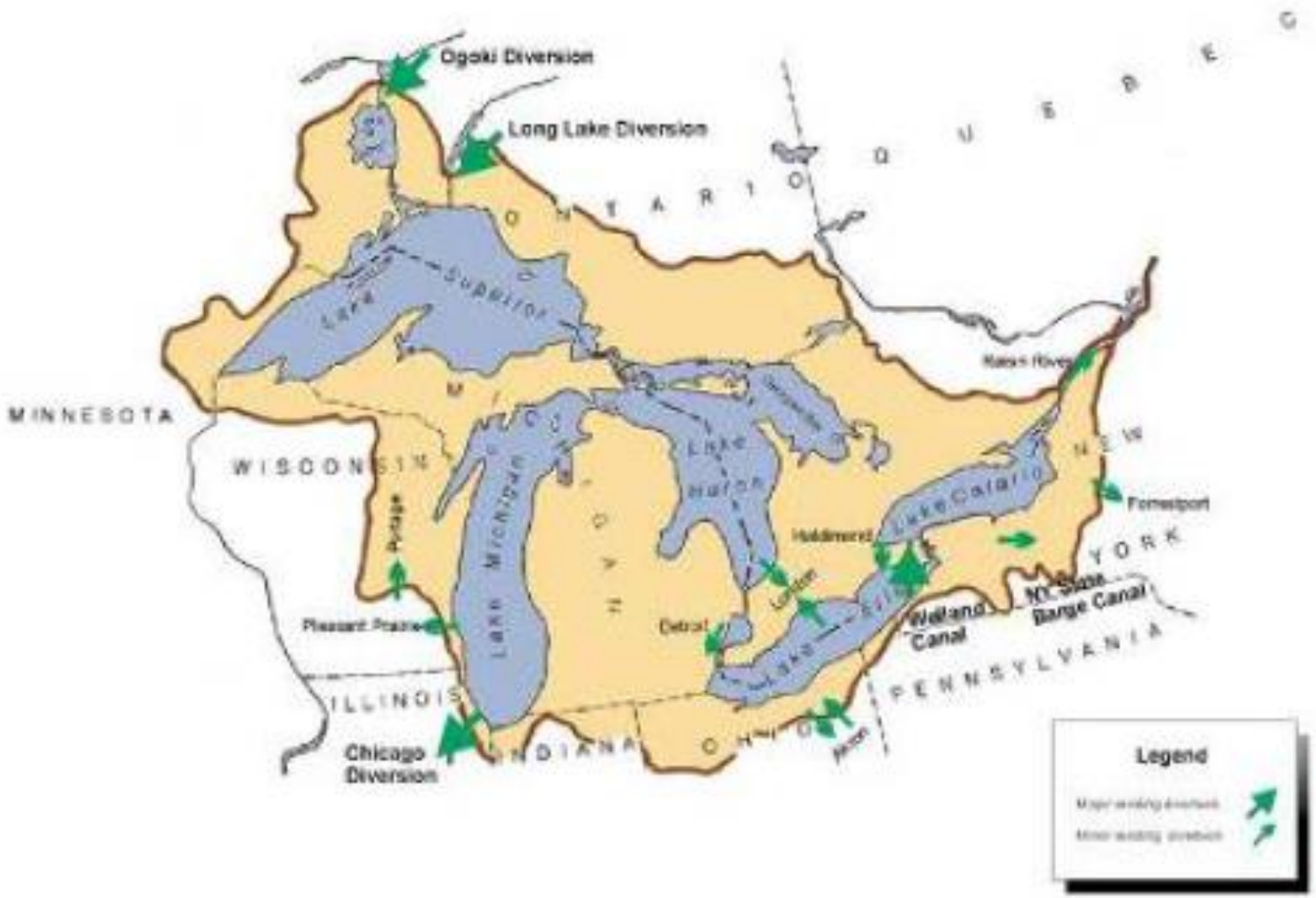
Slides from **Great Lakes Water Conservation Conference**
Jim Nicholas, Director USGS Water Science Center, Lansing, Michigan, October 18-19 2010

WATER USE IN THE GREAT LAKES REGION

GREAT LAKES WATERSHED



http://www.ec.gc.ca/grandslacs-greatlakes/03B3F448-D76E-46BC-95F3-72C4CF270237/gl_basin_e_1800.jpg



INTERNATIONAL JOINT COMMISION

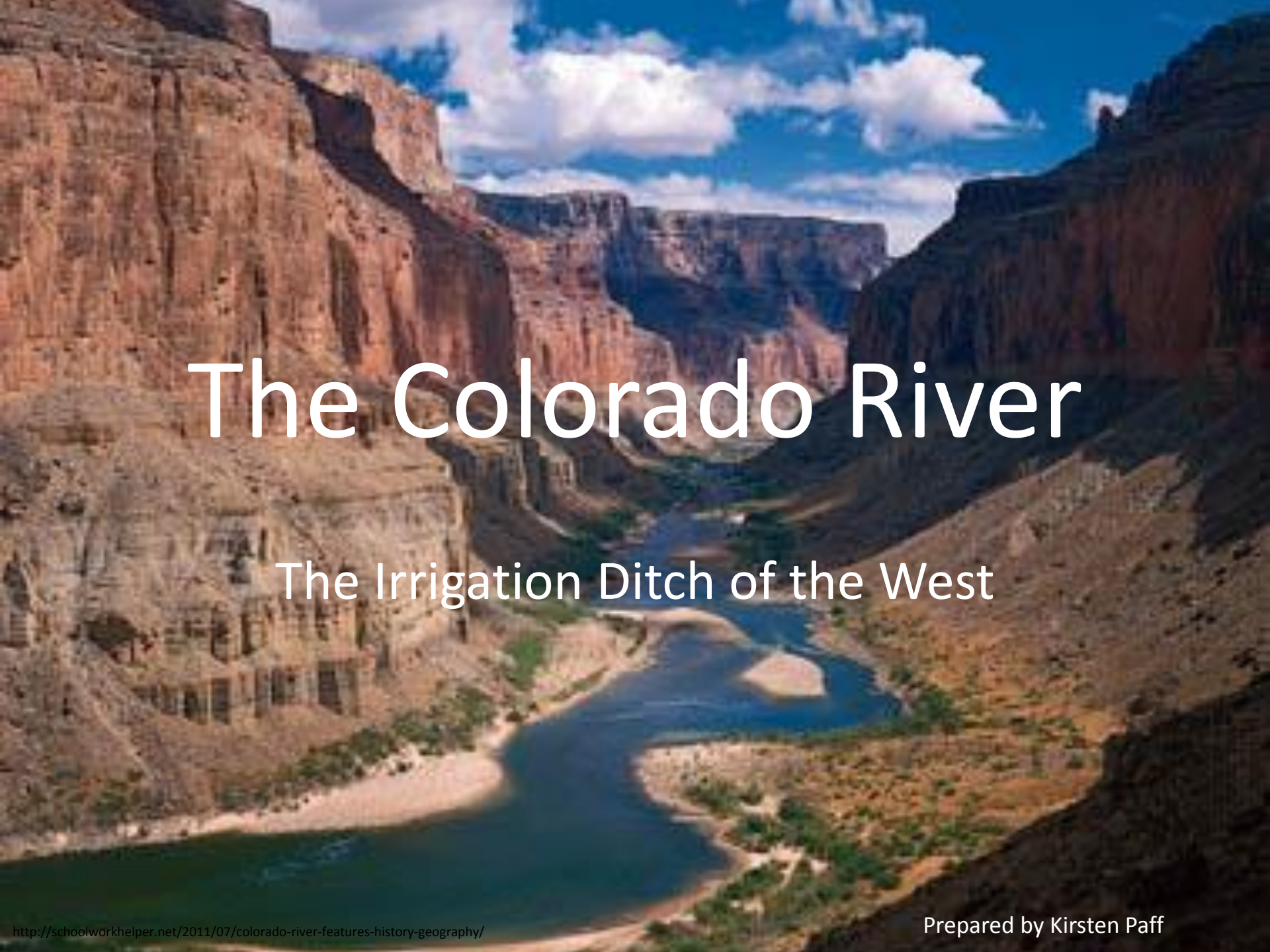
Existing diversions into and out of the Great Lakes Basin.

GREAT LAKES – ST LAWRENCE RIVER BASIN SUSTAINABLE WATER RESOURCES AGREEMENT

HYDROLOGY AND ECOLOGY— A ~~MISSING~~ NEW LINK

- Hydrology is a principal driver of aquatic ecology
- Hydrologists know little ecology and Ecologists know little hydrology
- Aquatic ecosystems are a focus of most water availability discussions
- How much water do we need to leave in the stream?

Slides from **Great Lakes Water Conservation Conference**
Jim Nicholas, Director USGS Water Science Center, Lansing, Michigan, October 18-19 2010



The Colorado River

The Irrigation Ditch of the West

http://schoolworkhelper.net/2011/07/colorado-river-features-history-geography/

Prepared by Kirsten Paff

Fact Sheet

Length: 2317 km (1,440 miles)

Drainage Area: 700,000 km^2

Avg. Yearly Flow: 17 km^3

Countries: United States, Mexico

Basin Population: 25 million

Source(s): The Colorado Rockies

(World Wildlife Fund, Colorado River; Schoolworkhelper, Colorado River: Features, History, Geography; Solomon, p. 331 and The Water Education Foundation, Colorado River Facts)

http://schoolworkhelper.net/2011/07/colorado-river-features-history-geography/

IMPERIAL VALLEY AGRICULTURE

http://www.superstock.com/stock-photos-images/1663R-23331

Charles Rockwood and George Chaffey had a dream. They dreamed of making a fortune by turning a desert valley locally known as the "valley of death" into an agricultural boomtown.
By 1901 they started construction on the first irrigation systems to the valley and swiftly renamed the place Imperial Valley.

The soil in the valley was good and thousands of farmers came flocking in, followed by merchants and tradesmen. New towns sprung up across the valley. Despite initial hardships due to failed canals and dams, the All-American Canal, completed in 1938, provided the fuel for a money making machine. Today the valley's agriculture is a billion dollar business and provides the country's salad crops.
(Pearce, p. 237-239)

http://blogs.denverpost.com/captured/2010/02/19/imperial-valley/920/

COLORADO RIVER

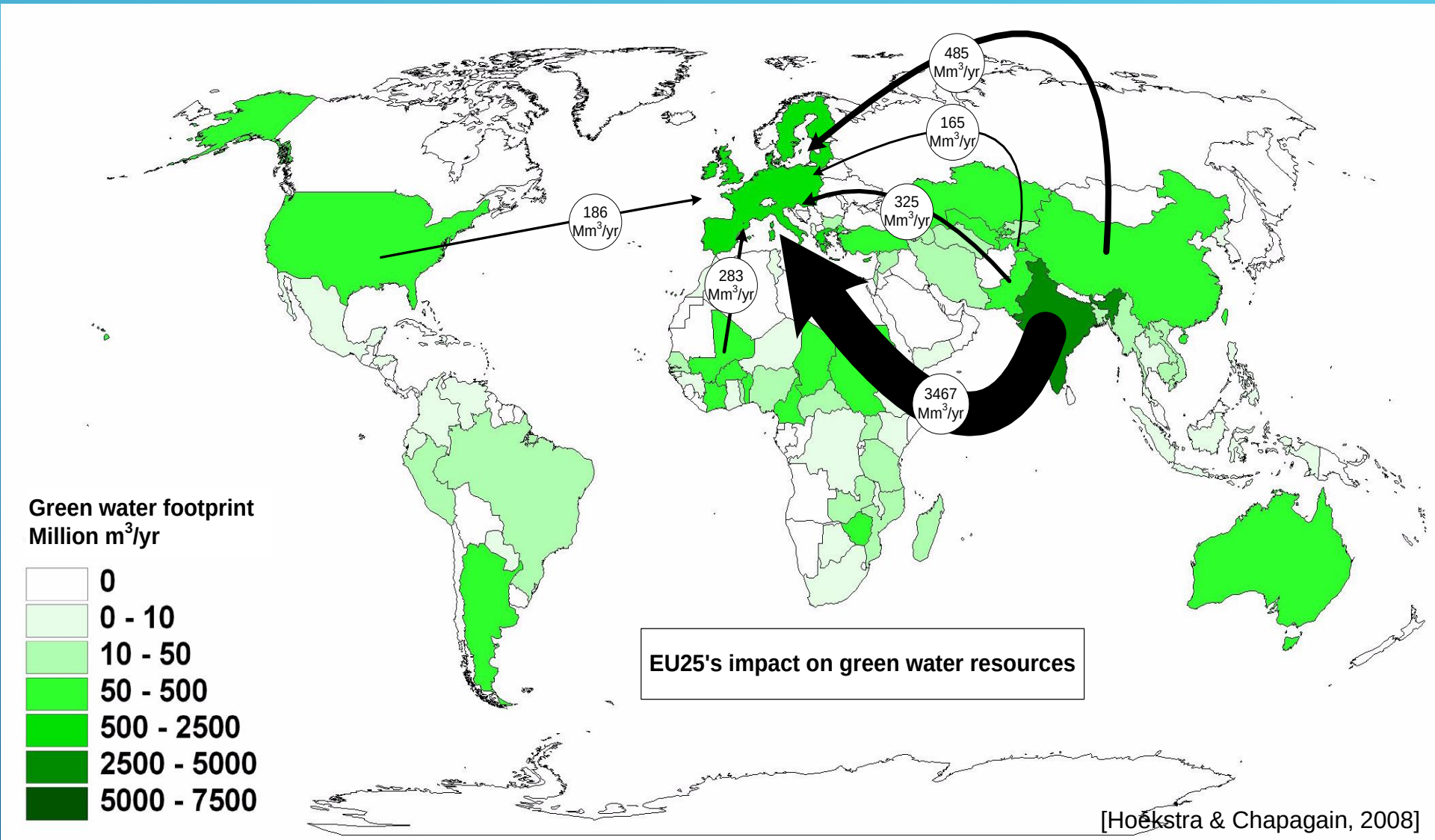
California irrigation from the Colorado River

http://aquafornia.com/wordpress/wp-content/uploads/2008/02/irrigation-_2-by-bor-pfs.jpg

- **River is drained dry**
  - before it reaches the ocean
- **Heavy irrigation use**
  - Colorado
  - Arizona
  - California
  - Mexico
- **City water supply**
  - Las Vegas
  - Phoenix
  - Tucson

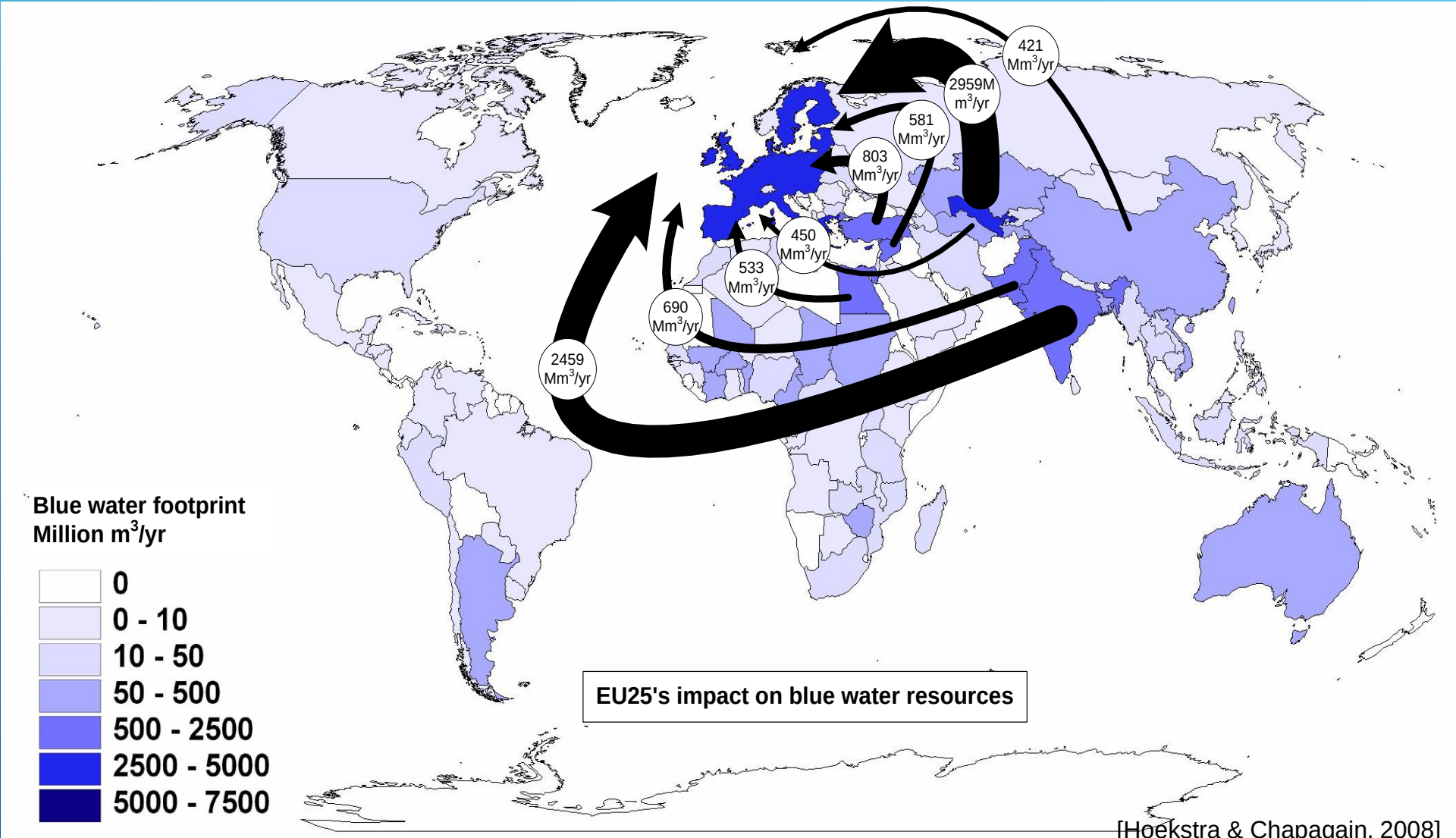
[Hoekstra & Chapagain, 2008]

Water footprint of EU's cotton consumption (green water)



[Hoekstra & Chapagain, 2008]

Water footprint of EU's cotton consumption (blue water)



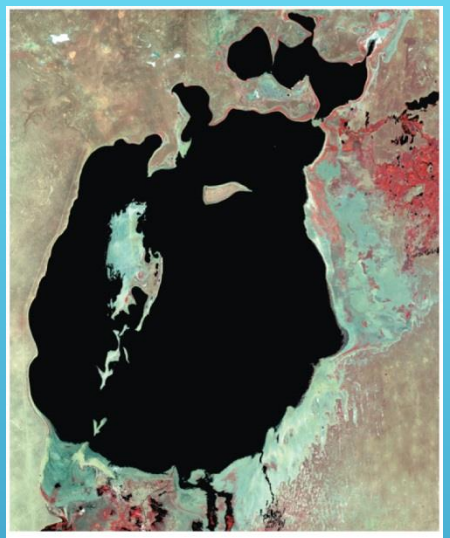
[Hoekstra & Chapagain, 2008]


The Caucasus and Central Asia
RUSSIA
KAZAKHSTAN
UZBEKISTAN
TURKMENISTAN
KYRGYZSTAN
TAJIKISTAN
AFGHANISTAN
PAKISTAN
INDIA
CHINA
IRAN
IRAQ
SYRIA
TURKEY
GEORGIA
ARMENIA
AZERBAIJAN
UKRAINE
BELARUS
JORDAN
SAUDI ARABIA
Black Sea
Caspian Sea
Aral Sea
Lake Balkhash
Moscow
Astana
Almaty
Tashkent
Bishkek
Dushanbe
Ashgabat
Tehrān
Kabul
Baku
Yerevan
T'bilisi
Baykonur Cosmodrome
Scale 1:19,000,000
Lambert Conformal Conic Projection, standard parallels 47°N and 62°N
Boundary representation is not necessarily authoritative.
802559AI (R00455) 1-00

THE ARAL SEA

THE ARAL SEA

- Once the fourth-largest lake on Earth
  - It lost 80% of its volume in 45 years
- The two rivers leading into the Aral Sea were diverted to irrigate cotton fields
- 60,000 fishing jobs are gone
- Pesticide-laden dust from the lake bed is blown into the air
- Cotton cannot save the region's economy



(a) Satellite image of Aral Sea, 1987

(b) Satellite image of Aral Sea, 2009

SIGNS OF GLOBAL WATER SCARCITY

Cotton for export

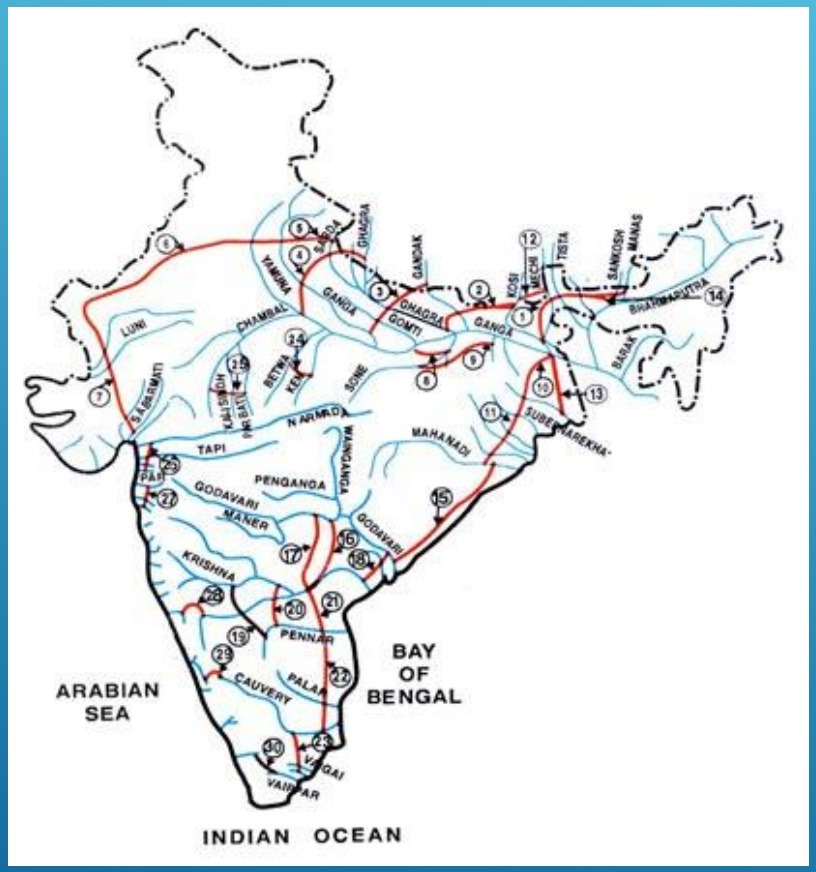
Former Aral Sea, Central Asia

IRRIGATION IN CHINA

Yellow River

- Yellow river used for irrigation
- River ran dry in 1972
  - For 15 days
- Since 1986 runs dry every year
- In 1997, dry for 227 days

INDIA RIVER INTERLINK PLAN



- **$200 billion plan**
  - to bring water to south India
- **Will link 36 rivers with canals**
  - Completed in 2016
- Potential benefits
  - Reduce flooding
  - Hydroelectric power
  - Irrigation

http://www.ben-center.org/riverMaps/RiverLinkingMainMap.jpg

ASWAN DAM, EGYPT

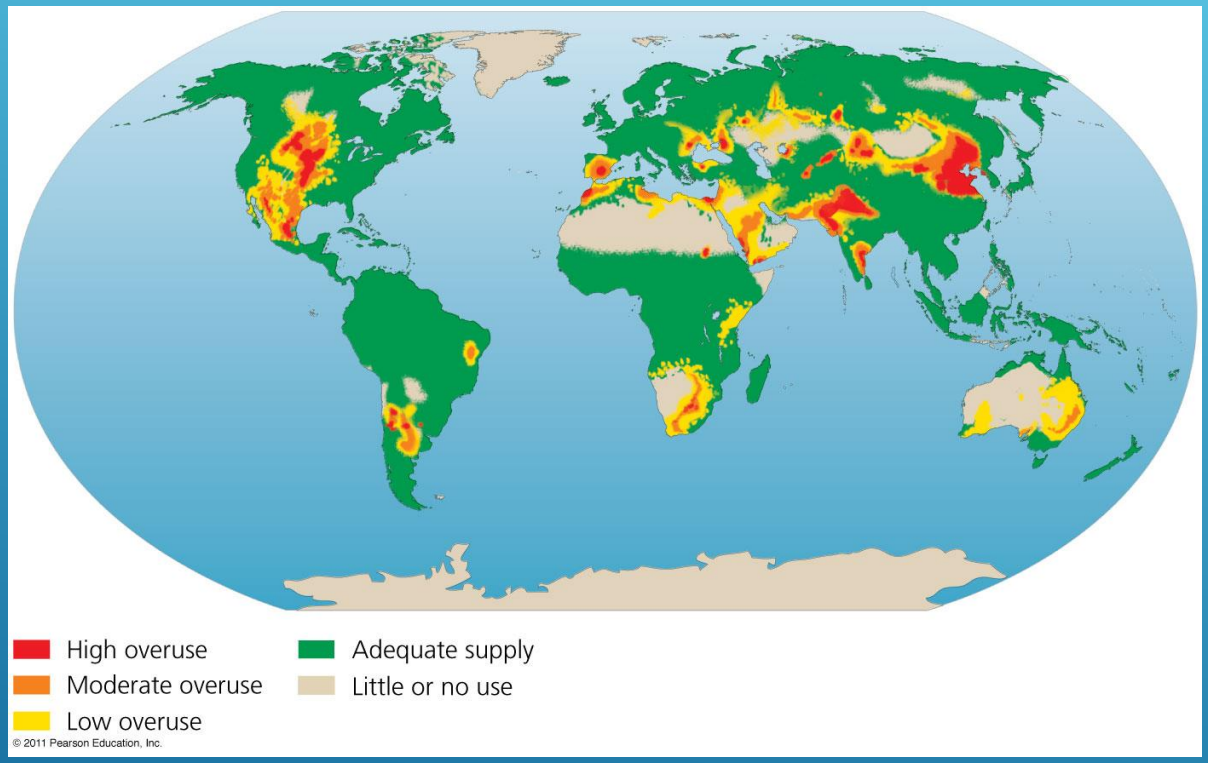
- Benefits
  - Controls flooding of Nile River
  - Hydroelectric power
- Problems
  - Fertile silt not deposited
    - Farmers must use fertilizer
  - Schistosomiasis increase
  - Nile delta receding
  - Increased salinity

http://www.2travel2egypt.com/sightseeing/images/aswandam.jpg

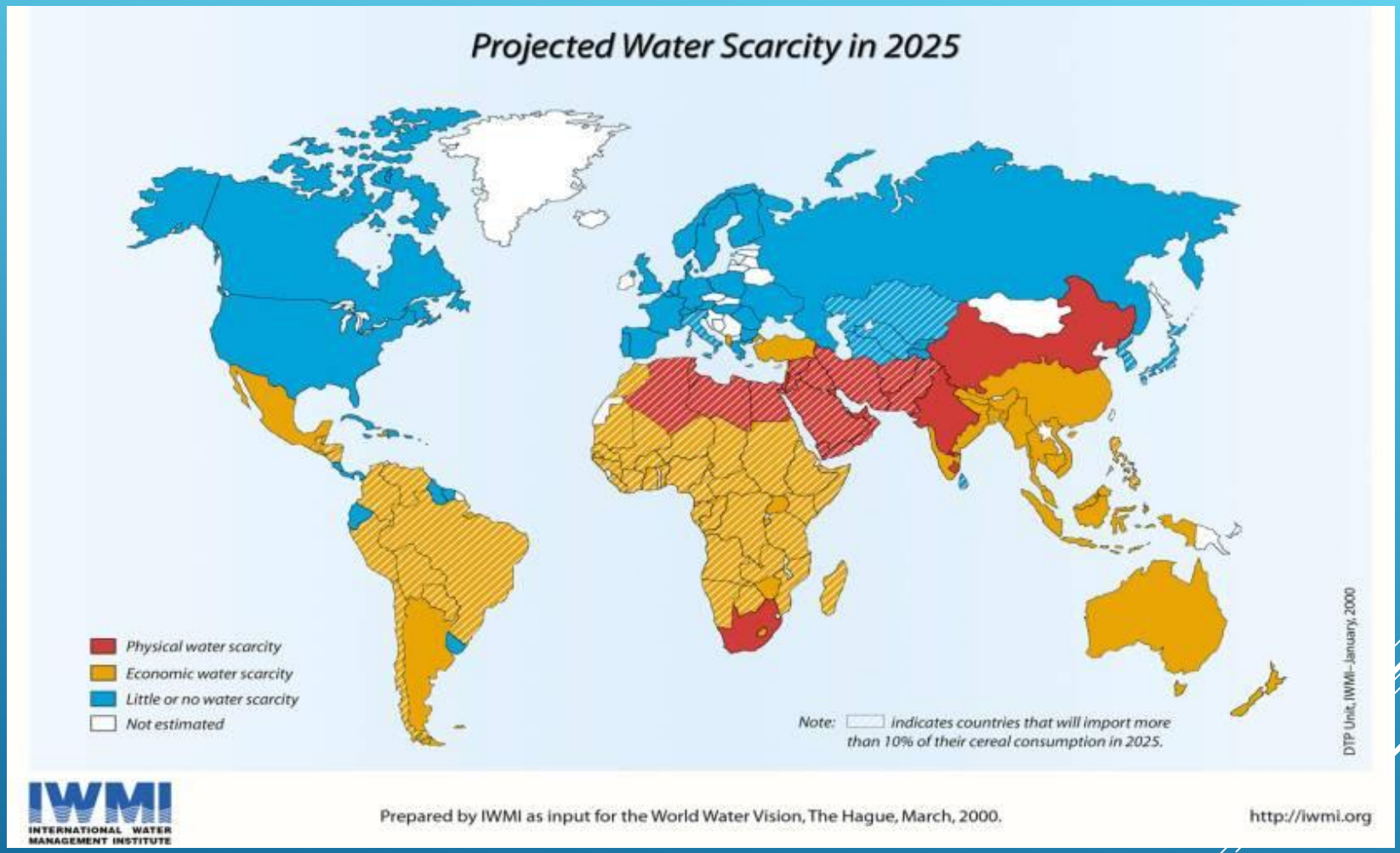
http://www.2travel2egypt.com/sightseeing/images/aswandam.jpg

WATER MINING

- 15–35% of water withdrawals for irrigation are unsustainable



- *Water mining* = withdraws water faster than it can be replenished


Projected Water Scarcity in 2025
Physical water scarcity
Economic water scarcity
Little or no water scarcity
Not estimated
Note: indicates countries that will import more than 10% of their cereal consumption in 2025.
DTP Unit, IWMI–January, 2000
IWMI
INTERNATIONAL WATER MANAGEMENT INSTITUTE
Prepared by IWMI as input for the World Water Vision, The Hague, March, 2000.
http://iwmi.org

HYPOXIA IN THE GULF

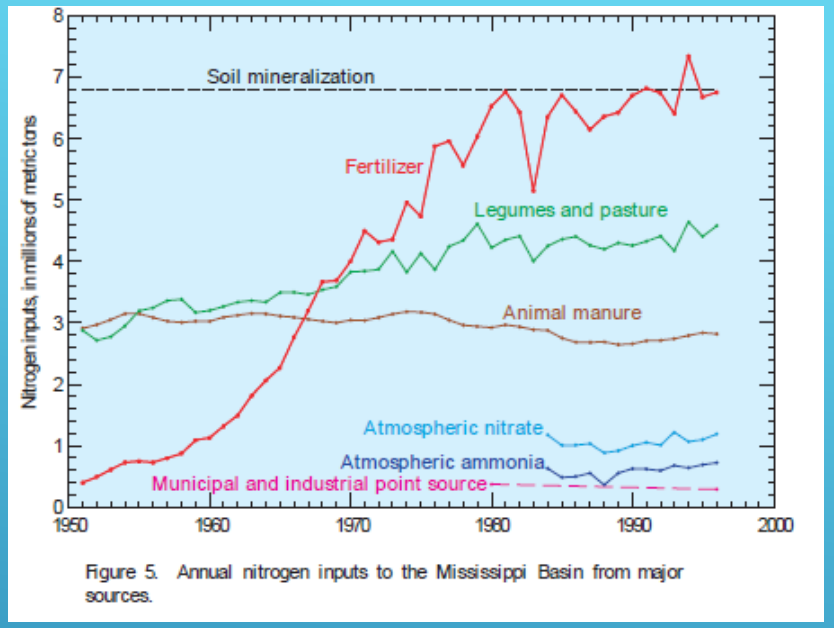
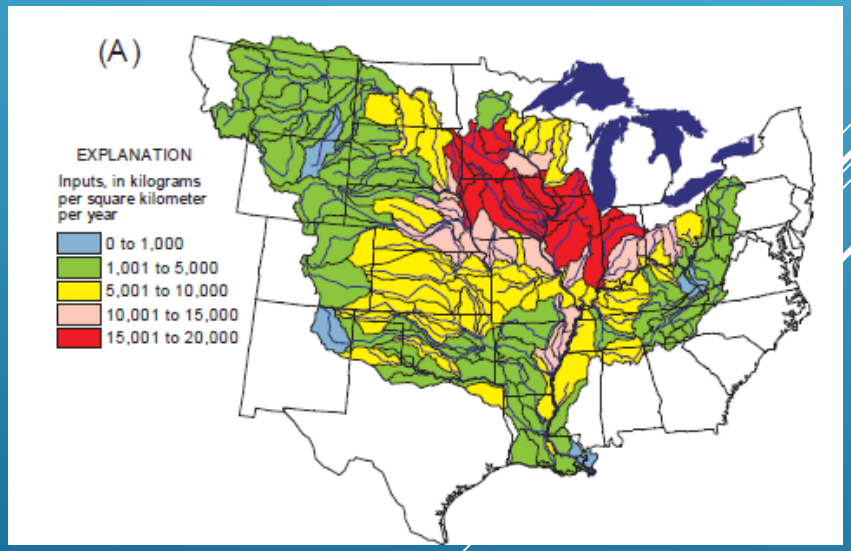


Figure 5. Annual nitrogen inputs to the Mississippi Basin from major sources.



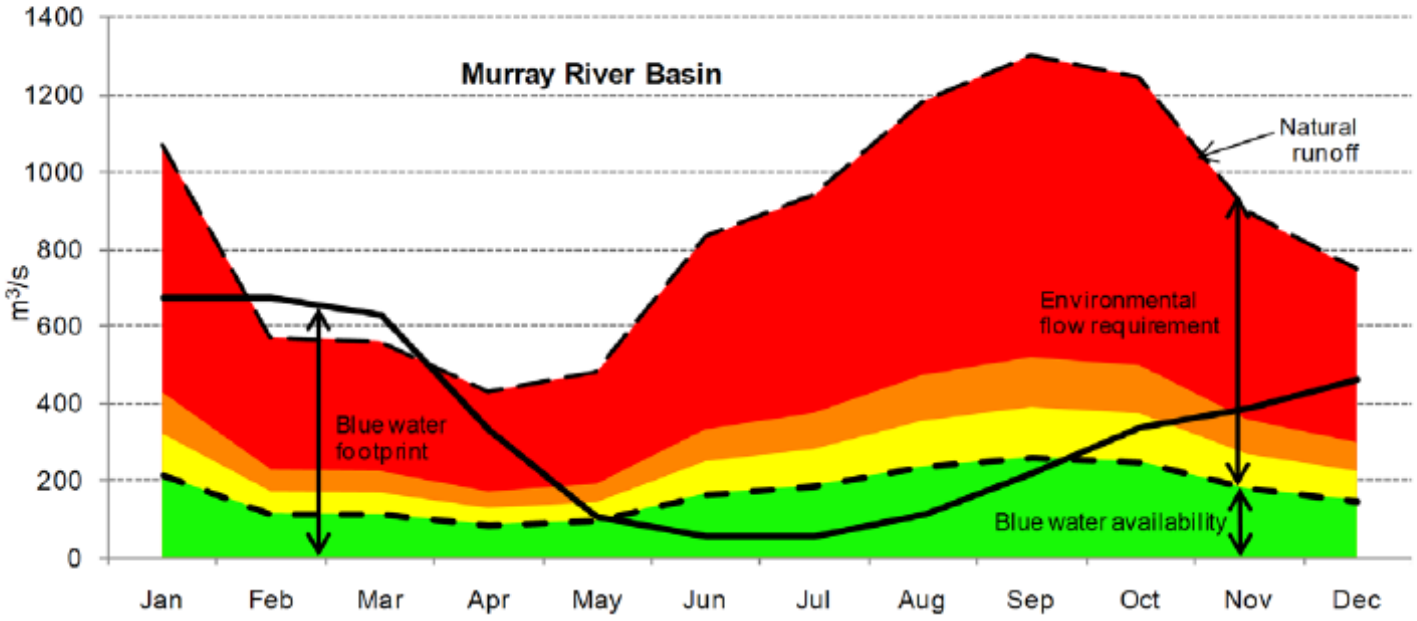


Figure 3. Water scarcity over the year for the Murray-Darling River Basin in Australia (average for the period 1996–2005). Net available water – that is natural runoff minus environmental flow requirement – is shown in green. From October until May, the blue water footprint exceeds net available water; in these months, the presumptive environmental flow requirement is not met. When the blue water footprint moves into the yellow, orange and red colors, water scarcity is moderate, significant and severe, respectively.
doi:10.1371/journal.pone.0032688.g003

MURRAY-DARLING RIVER BASIN

- What can be done?

Make better use of ‘green water’

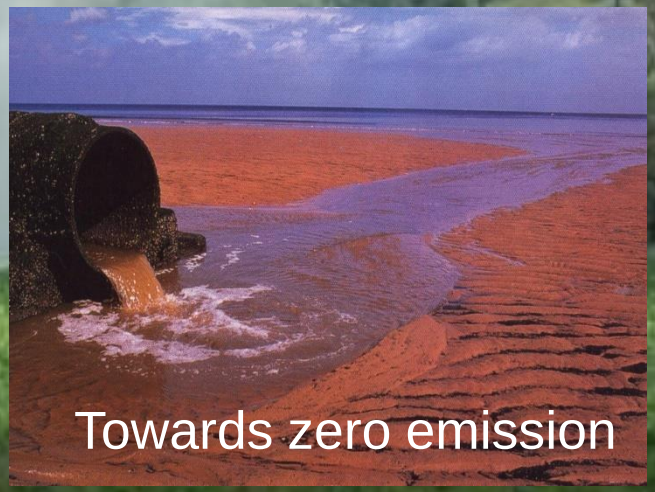
Increase water productivity in rain-fed agriculture

Efficient Use of ‘blue water’

Towards precision irrigation

Reduce Grey water footprint ↓ zero

Can we use water for irrigation, industry and domestic use in a sustainable way without impacting the environment?



UNITED NATIONS WATER POLICY

http://www.un.org/waterforlifedecade/pdf/human_right_to_water_and_sanitation_milestones.pdf

On 28 July 2010, through Resolution 64/292, the United Nations General Assembly explicitly recognized the human right to water and sanitation and acknowledged that clean drinking water and sanitation are essential to the realisation of all human rights. The Resolution calls upon States and international organisations to provide financial resources, help capacity-building and technology transfer to help countries, in particular developing countries, to provide safe, clean, accessible and affordable drinking water and sanitation for all.

USAID, Water and Food Security

http://blogs.cfr.org/coleman/2013/04/25/usaid-water-and-food-security/

WATER DEVELOPMENT STRATEGY

Isobel Coleman Apriil 25, 2013

WATER RESOURCES AND AGRICULTURAL AND BIOLOGICAL ENGINEERING

Questions:

- **Who's water is it?**
- **How will the availability of Water Resources affect ABE Professionals?**
- **How can we begin to address these issues?**
- **Are the issues technological ,Social Economic?**

Challenge !!!

- **What is your water footprint?**
  - **http://www.waterfootprint.org/?page=cal/WaterFootprintCalculator**