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IMPROVING ENGINEERING EDUCATION

Water

The Cambridge-MIT Institute

UNIVERSITY OF CAMBRIDGE

This slide show is based on a lecture originally given by Prof. Charles Ainger, developed under the Royal Academy of Engineering Visiting Professors Scheme.

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version 4

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The Blue Planet?

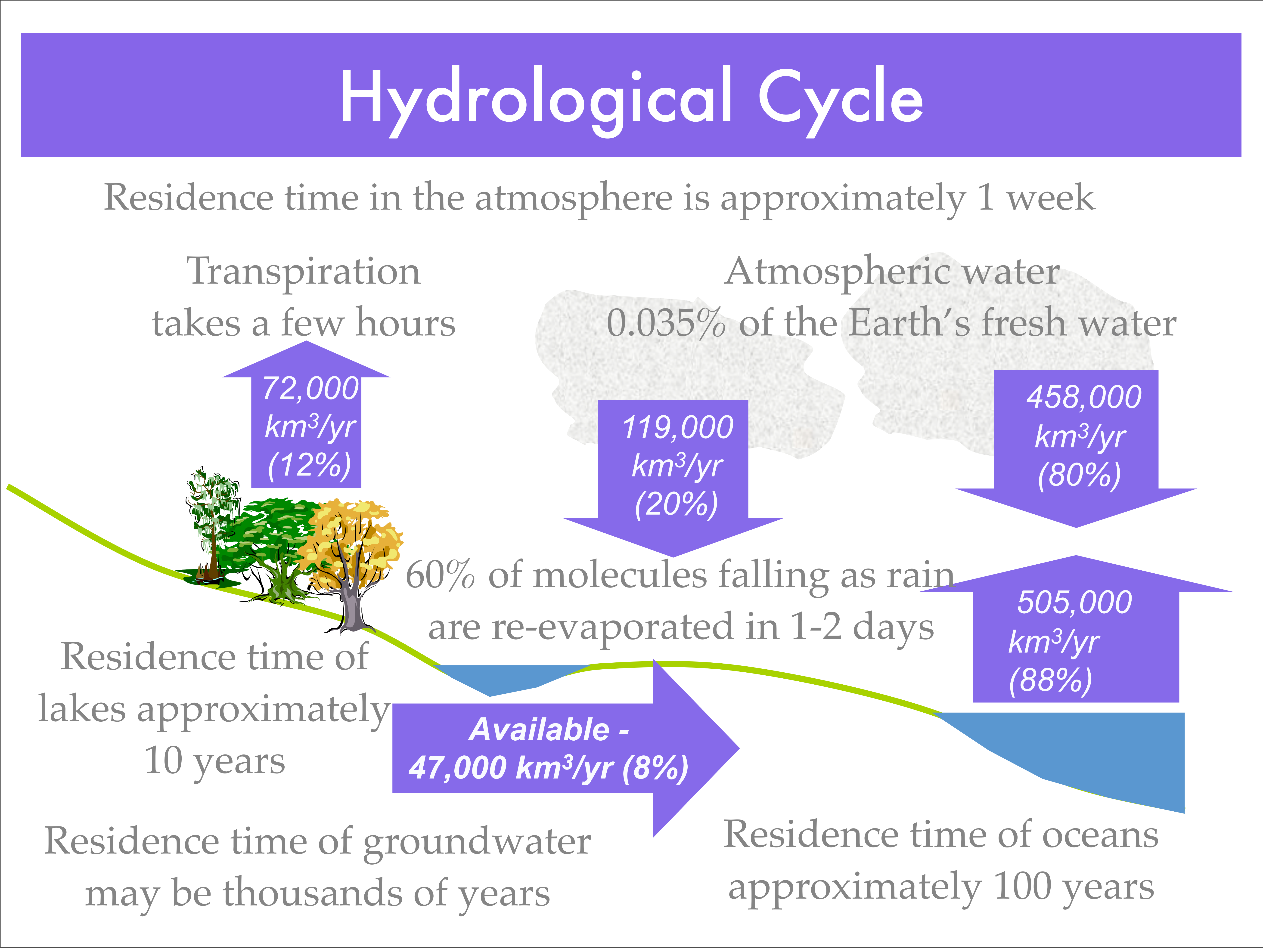
Total volume of water on Earth (100%) = 1,386,000,000 km^3

Total freshwater (2.5%) = 35,029,000 km^3

Available freshwater = 200,000 km^3

The image we have of the Earth as the ‘Blue Planet’ is slightly misleading when we consider the water available for our use.
Most of the Earth is covered by seas and oceans accounting for over 97% of total water on the planet, leaving less than 3% of the planet’s water that is not salty. Of the freshwater that is present, “2 percent is locked in icecaps and glaciers, and a large proportion of the remaining 1 percent lies too far underground to exploit” Postel, Sandra (1992) “The Last Oasis: Facing Water Scarcity” Earthscan, London, p27
For the vast majority of human uses – be that domestic, industrial, or agricultural – we require fresh water.

Total volume = 1.40 billion cubic kilometres
Freshwater = 35 million cubic kilometres (less than 3% of all water)
Usable freshwater approx. 200,000 cubic kilometres (less than 1% of freshwater)
Volumes taken from: Gleick, Peter (2001) “The World’s Water: The Biennial Report on Freshwater Resources” Island Press, p21 Table 2.1:major stocks of water on Earth.

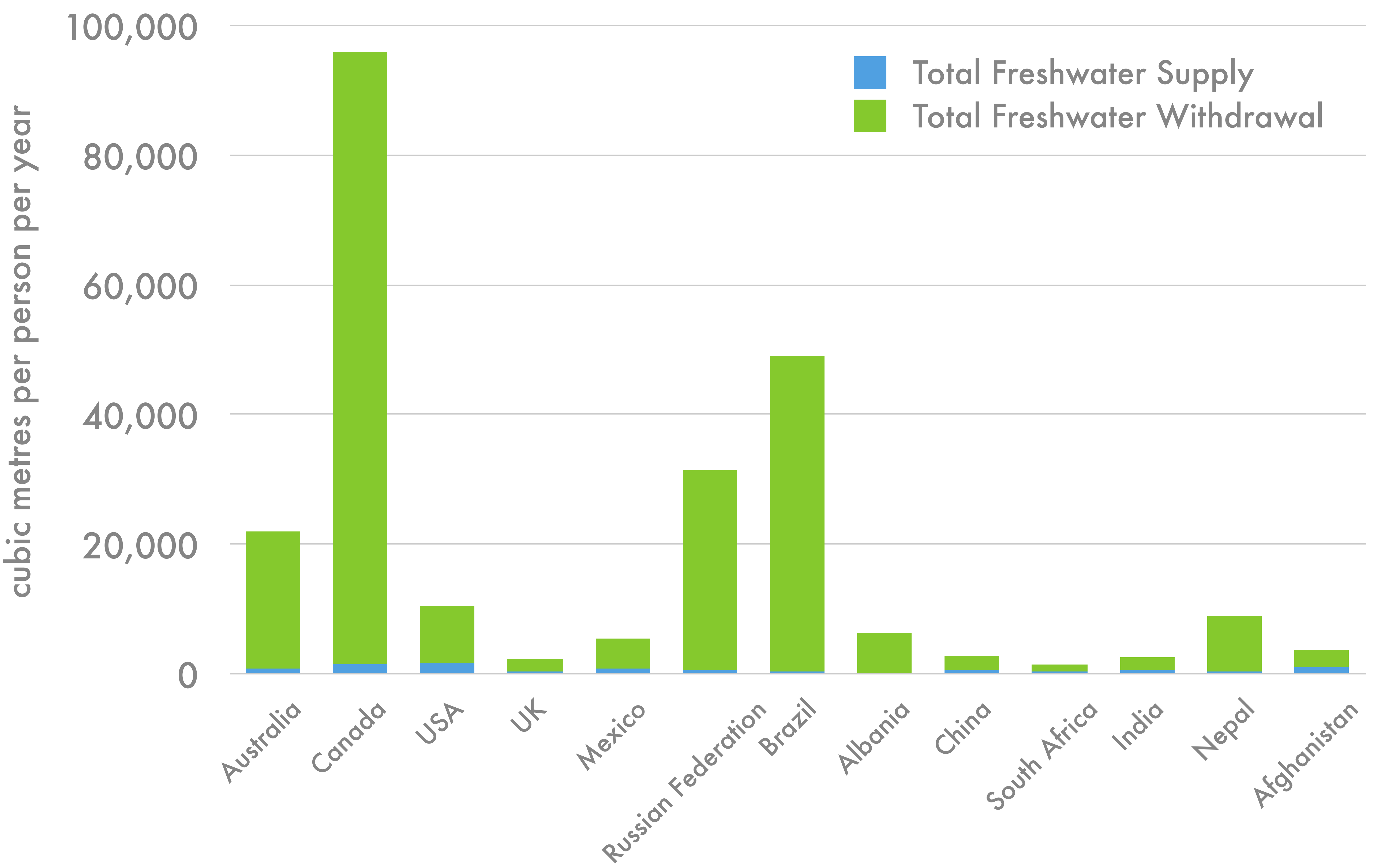


Annually, around 505,000km^3 is evaporated from the oceans, and 72,000km^3/year is evaporated from land surfaces to join the hydrological cycle. This gives a total of around 577,000km^3/year active in the global water cycle. Of this total, approximately 458,000km^3/year (80%) falls back onto the oceans and only 20% (119,000km^3/year) falls onto the land.
Of the 20% freshwater falling on land as precipitation, most is transpired back into the atmosphere almost immediately, leaving only 8% of the total active volume on the ground. Much of this forms groundwater that may become inaccessible and/or polluted and surface water which may become polluted.

Globally, 7,000km^3 more water is stored on land in March than in September when 600km^3 more is stored in the atmosphere than in March.
Source: Gleick, Peter (2001) "The World's Water: The Biennial Report on Freshwater Resources" Island Press, p22

Atmospheric water volume taken from Ball, Philip (1999) "H_2O: A Biography of Water" Pheonix/Orion, London.

Water Supply



In many countries, only a very small proportion of available water is actually extracted for use. The total resource that is available to a country or a region is usually termed the 'supply'. The amount that we extract for use is termed the 'withdrawal'.

Graph:
Annual freshwater resources data taken from Gleick, Peter (2003) "The World's Water: The Biennial Report on Freshwater Resources" Island Press, pp239-242, Table 1: Total Renewable Freshwater Supply, by Country (2002 Update)
Annual freshwater withdrawals data taken from Gleick, Peter (2003) "The World's Water: The Biennial Report on Freshwater Resources" Island Press, pp245-251, Table 2: Freshwater Withdrawals, by Country and Sector (2002 Update)

Countries arranged in descending order of Human Development Index rank as taken from United Nations Development Programme (2005) "The Human Development Report – International Cooperation at a Crossroads: Aid, trade and security in an unequal world" Oxford University Press, Oxford and New York

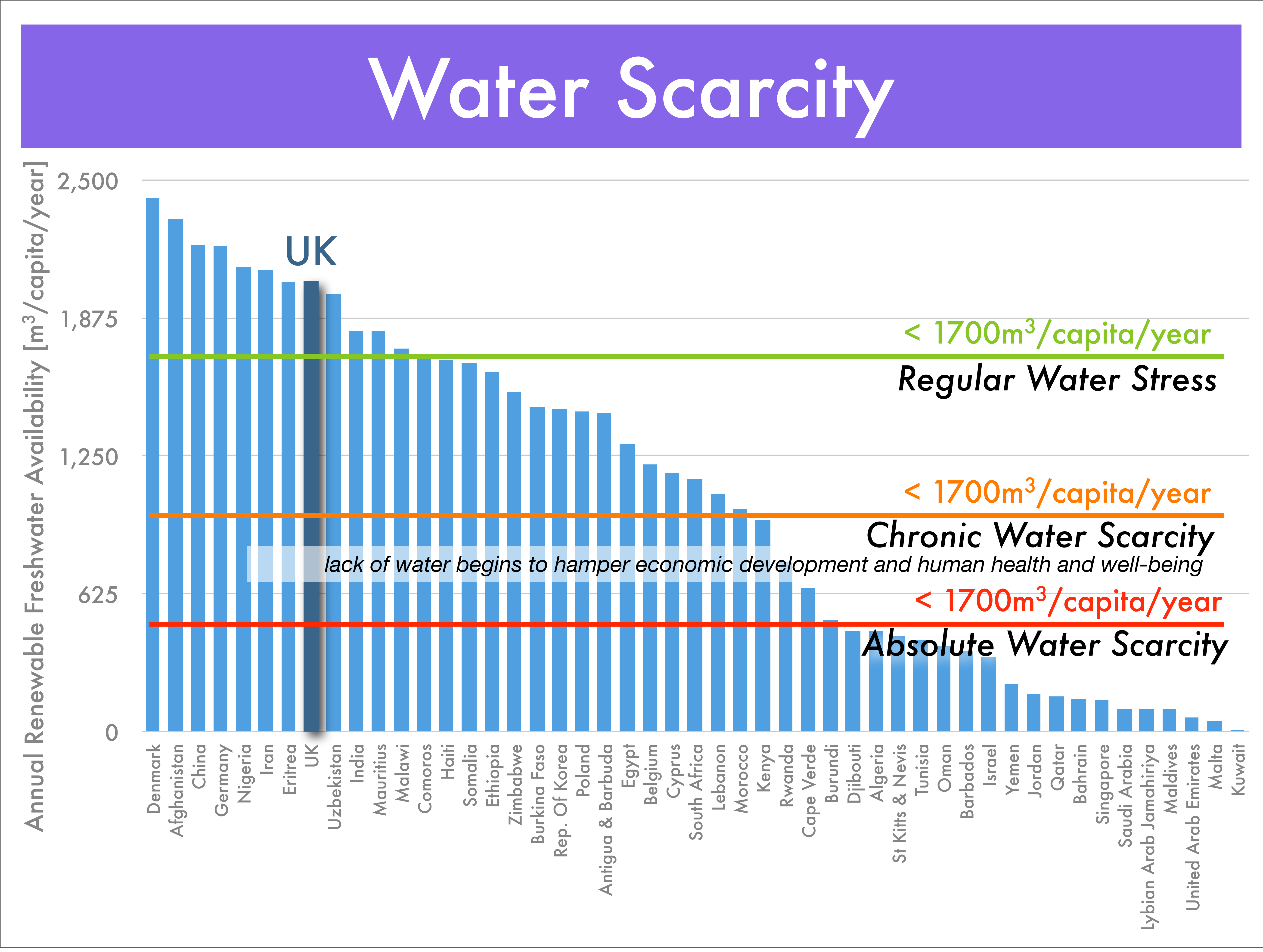
The role of engineers

"The engineers that help realise these water supply opportunities will be this century's most valued peace keepers"

Andrew Mylius

NCE cover story, 20th April 2000, "Keeping the Peace" by Andrew Mylius.
'Competition for scarce water resources is increasingly a source of political tension. Engineering can play a major role in defusing it.'

Mylius, Andrew (2000) "Keeping the Peace" New Civil Engineer, 20th April 2000, pp 14-15



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Annual Renewable Fresh Water (cubic metres per capita per year/day)		Level of water stress
>1,700 /	4.65	Occasional or local water stress
1,000 – 1,700 /	2.74 - 4.65	Regular water stress
500 – 1,000 /	1.36 - 2.74	Chronic water scarcity (lack of water begins to hamper economic development and human health and well-being)
<500 /	1.36	Absolute water scarcity

By widely-used water stress definitions the UK is currently subject to occasional or local water stress. This is evident from our infrequent experiences of hosepipe bans and pleas for water conservation.
As climate changes and precipitation patterns alter, the occurrence of water stress is predicted to become more widespread. This, combined with population increases in many places, will result in more extensive water shortages relative to demand. As with all country data this is aggregated average information. Within these countries, particular regions may be relatively more water-rich or water-poor. For example, the South East of England is considerably more water-stressed than Northern Scotland.

Graph:
Annual freshwater resources data taken from Gleick, Peter (2003) "The World's Water: The Biennial Report on Freshwater Resources" Island Press, pp239-242, Table 1: Total Renewable Freshwater Supply, by Country (2002 Update)
Population data from World Bank (2003) "World Development Indicators 2003" The World Bank, Washington, 2002 figures
Definitions of limits of water stress from Gleick, Peter (2003) "The World's Water: The Biennial Report on Freshwater Resources" Island Press, p99, Table 4.2: Water Stress Definitions

It is important to get a feel for what this actually means. Absolute scarcity in these terms (500m3/person/year) is less than 1.5 cubic meters of water per person per day. This seems like a lot, but usually we are only thinking about the domestic portion of water use rather than the per capita water availability necessary to maintain a functioning economy. Lack of water availability can inhibit industrial and economic development.

For general human health requirements, volumes required are as follow:
Normal Recommended 50 litres per person per day
Minimum Recommended 30 litres per person per day (5 litres for cooking and drinking, 25 litres for hygiene)
Emergency Sphere guidelines 15 litres per person per day
Sphere Project (2000) "Humanitarian Charter and Minimum Standards in Disaster Response" Oxfam Publishing, p30, available at http://www.sphereproject.org

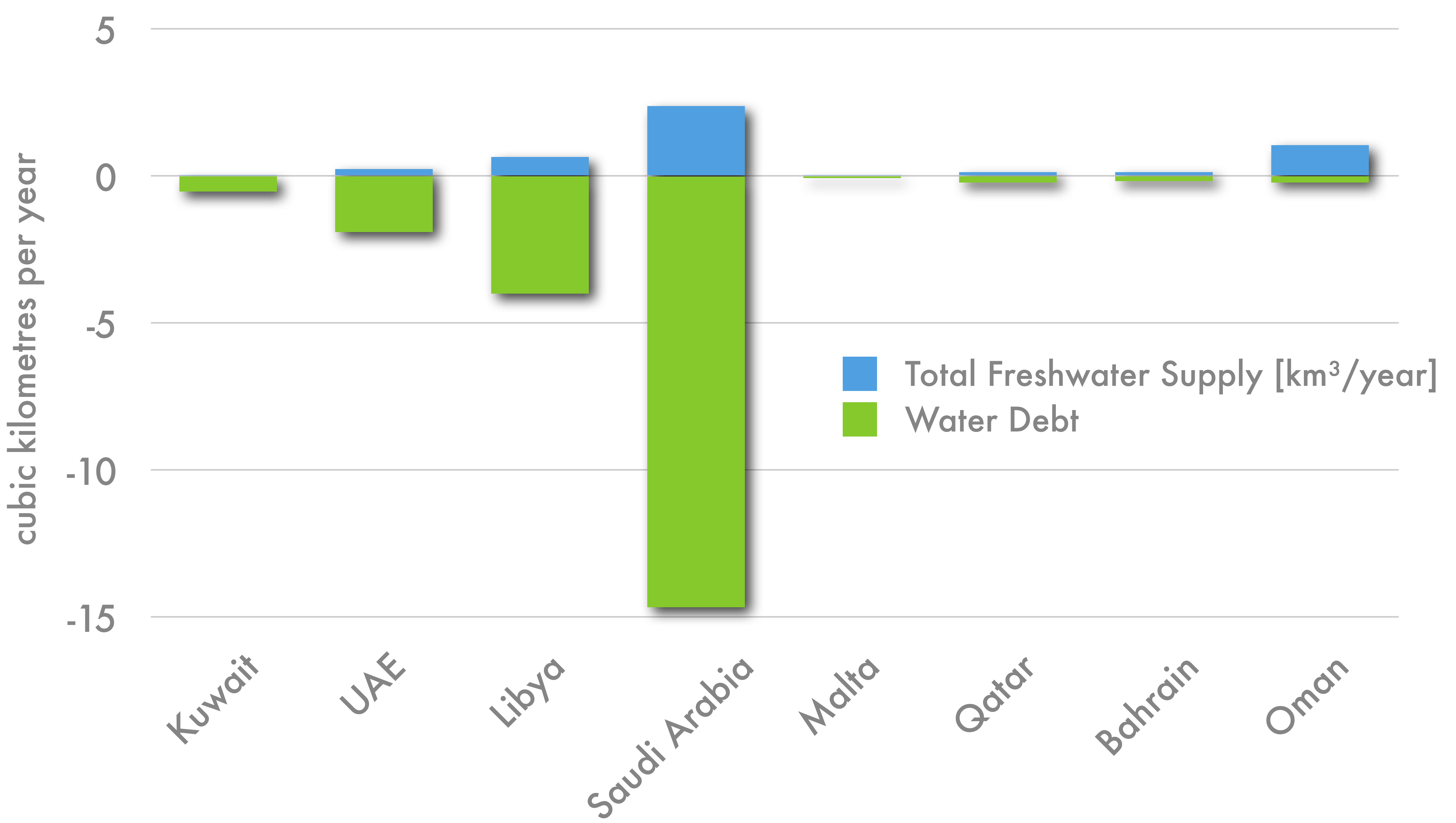
Some of the most water scarce countries are small island nations such as Malta (50m^3/capita/year) and the Maldives (105m^3/capita/year), Singapore (144m^3/capita/year), and those of the Middle East region: Kuwait (10), UAE (66), Libya (108), Saudi Arabia (109), Bahrain (149), Qatar (164), Jordan (174), Yemen (220), Israel (339). High demand for industrial purposes and meeting domestic needs of increasing populations lead to over-use of water in some of these places.

Water debt

- If the amount of ground water withdrawn exceeds natural inflow, there is a water debt
- In such cases, water should be considered as a non-renewable resource that is being mined.

As the world's population and industrial production of goods increase, the use of water will also accelerate. The world per capita use of water in 1975 was about 700m^3 /year giving a total human use of 3850 km^3/year. Now the world use of water is about 6000 km^3 / year, which is a significant fraction of the naturally available fresh water.
Source: 'Environmental Science - Earth as a Living Planet', Daniel B Botkin and Edward A Keller. pub. John Wiley & Sons 2005

Water debt



Some water-stressed countries withdraw considerably more water than is renewed annually, leading to significant ‘water debt’.

Graph: Annual freshwater resources data taken from Gleick, Peter (2003) “The World’s Water: The Biennial Report on Freshwater Resources” Island Press, (2002 Update)

Countries arranged in descending order of water debt severity.

Kuwait is currently the world’s most water scarce nation and also the worst water debt country, with an annual renewable freshwater supply of approximately 0.02km^3/year and an annual freshwater withdrawal of around 0.54km^3/year (2700% of available renewable supply). Saudi Arabia extracts the greatest volume of water (14.62 km^3/year) beyond it’s renewable supply (2.4km^3/year) and uses 7 times more than it has available, but UAE (1.91km^3/year debt and consumption 10 times renewable supply) and Libya (4km^3/year and nearly 8 times supply) are also bad water debtors.

However, even relatively water-rich countries can exceed their renewable supply; Uzbekistan has approximately 50.4km^3/year renewable available freshwater, but withdraws around 58.05km^3/year (115% of available supply). Uzbekistan has experienced the detrimental effects of this unsustainable over-use of freshwater and has witnessed the deterioration of the Aral Sea and its associated industry.

In comparison:
USA withdraws only around 20% of available renewable supply
UK withdraws only around 10% of available renewable supply
Canada withdraws only around 1.5% of available renewable supply
Brazil withdraws only around 0.5% of available renewable supply

Water-debt countries and regions meet their water withdrawals beyond the renewable supply in a number of ways, including: drawing water across political boundaries, or depleting ‘fossil aquifers’ in some cases causing not only extraction of ancient groundwater reserves, but also causing irreparable collapse of the geological structure, thus preventing future recharge.

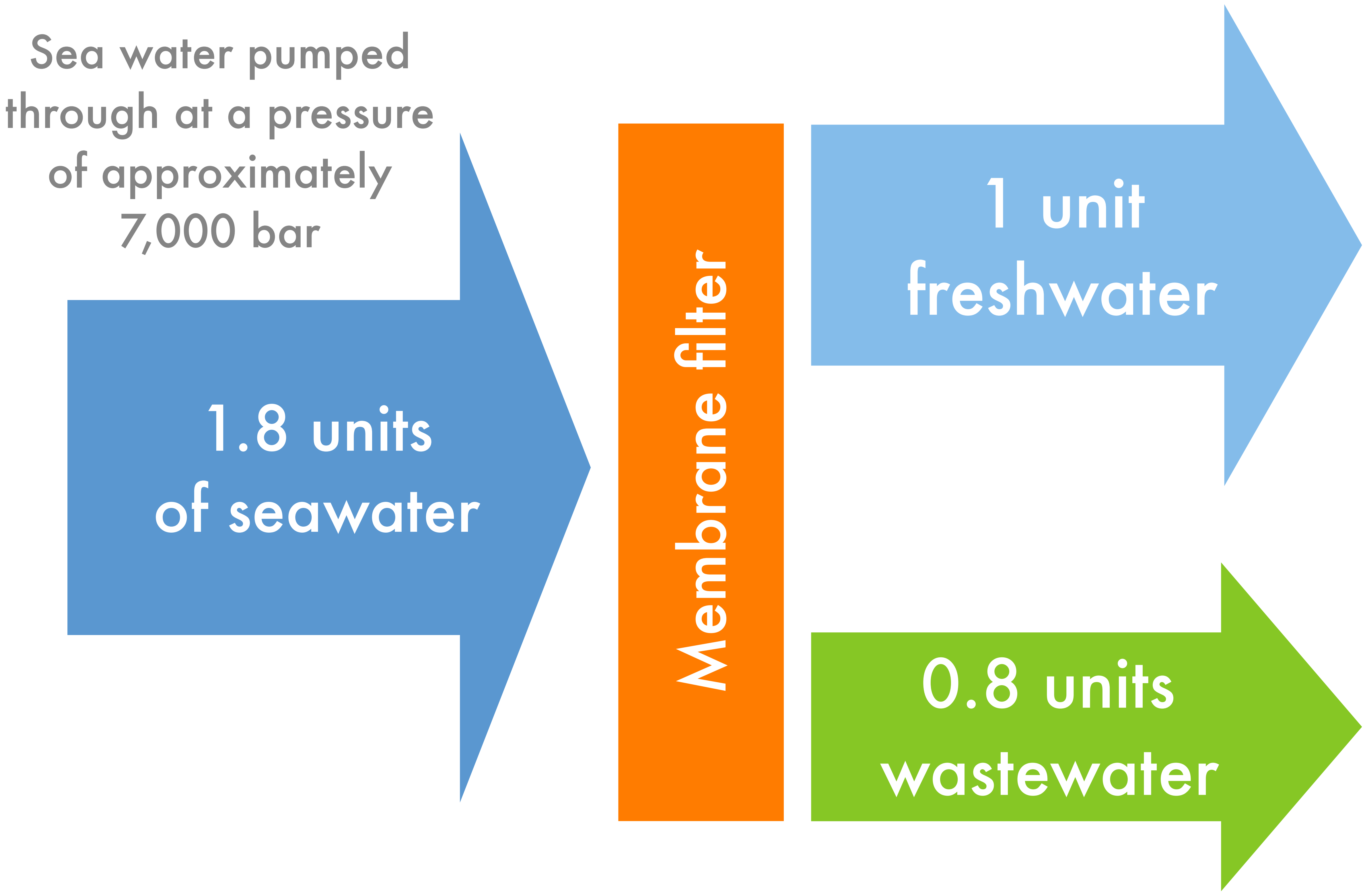
Energy-rich but water-poor countries, such as the water-stressed and water-debt oil-producing countries of the Middle East may use desalination techniques to produce freshwater from sea water.

Desalination

- Seawater contains about 3.5% salt
- One cubic meter of sea water contains around 40kg of salt
- To produce 'freshwater' the salt content must be reduced to less than 0.05%

The process of desalination is described on the next slide. As well as being costly in terms of energy, it also has environmental impacts: discharge of very salty water may locally kill plants and animals intolerant to salt and alter the habitat and local ecosystems.

Desalination



The reverse osmosis method, the most widely used for desalination of sea water, requires large amounts of energy in order to push source water through a membrane at a pressure of around 7,000 bar (100,000psi). The high-tech membranes are themselves expensive, although costs are reducing as the technology matures and the market grows. They require cleaning with chemicals, which then contribute to the problem of waste disposal together with the excessively salty wastewater produced by the process.

Only those countries which are water-poor but energy-rich, such as oil-producing nations in the Middle East, have the necessary combination of "desperation, wealth, and cheap energy" that make desalination worth consideration.

Desalination is currently limited to locations with a specific concentration of factors. Desalination plants on a large scale have high capital costs and high running costs. Many of the existing plants have been built adjacent to coastal power plants in order to consolidate impact and reduce costs associated with power transmission and water intake pipe work.

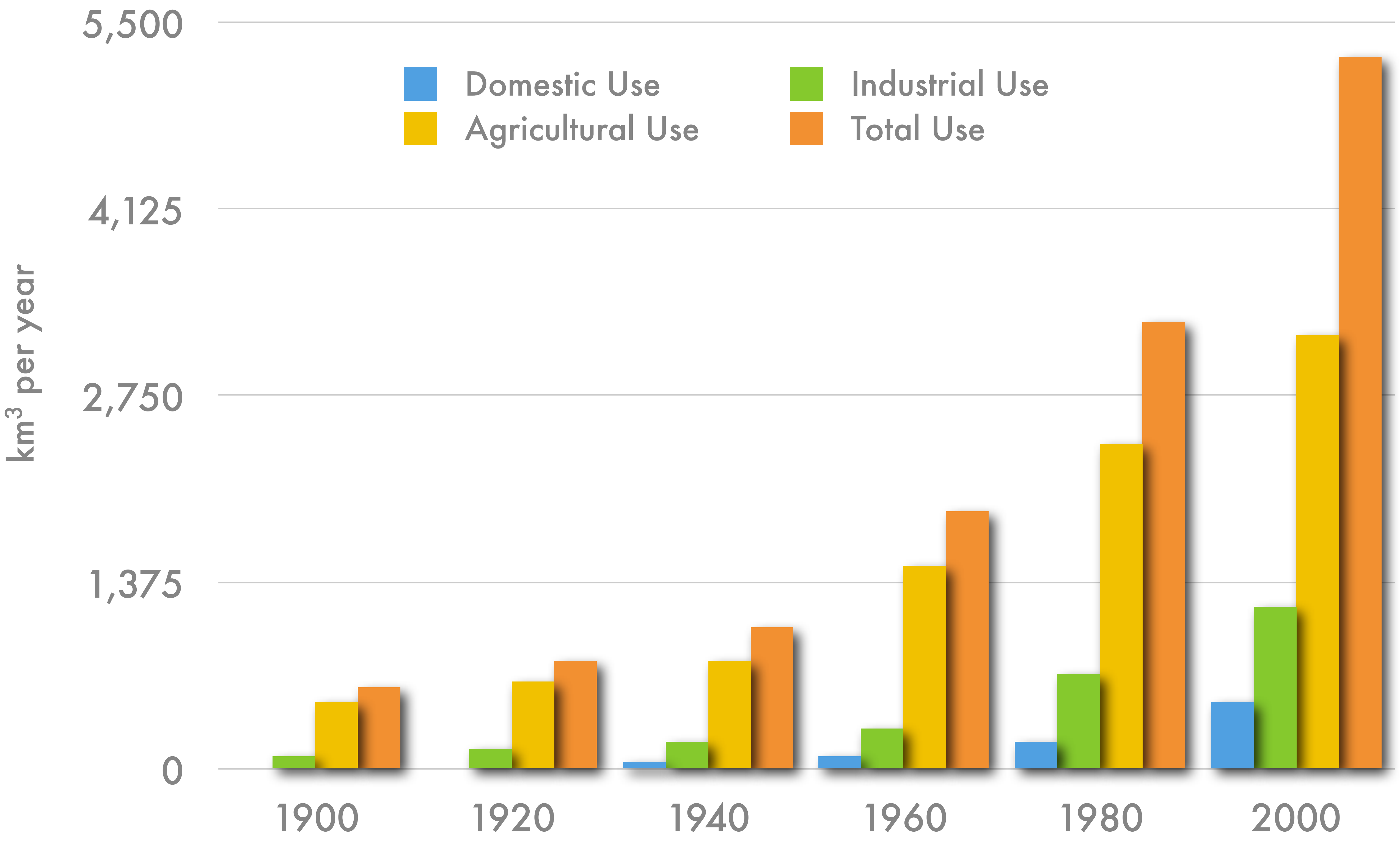
McDonald, Bernadette & Douglas, Jehl (eds.) (2003) "Whose Water Is It?: The unquenchable thirst of a water hungry world" National Geographic Society, Washington, pp199-211

"Desalinating brackish water – which is too salty to drink but much less salty than ocean water – is among the most rapidly growing uses of desalination. … it typically costs less than half as much as seawater desalination."

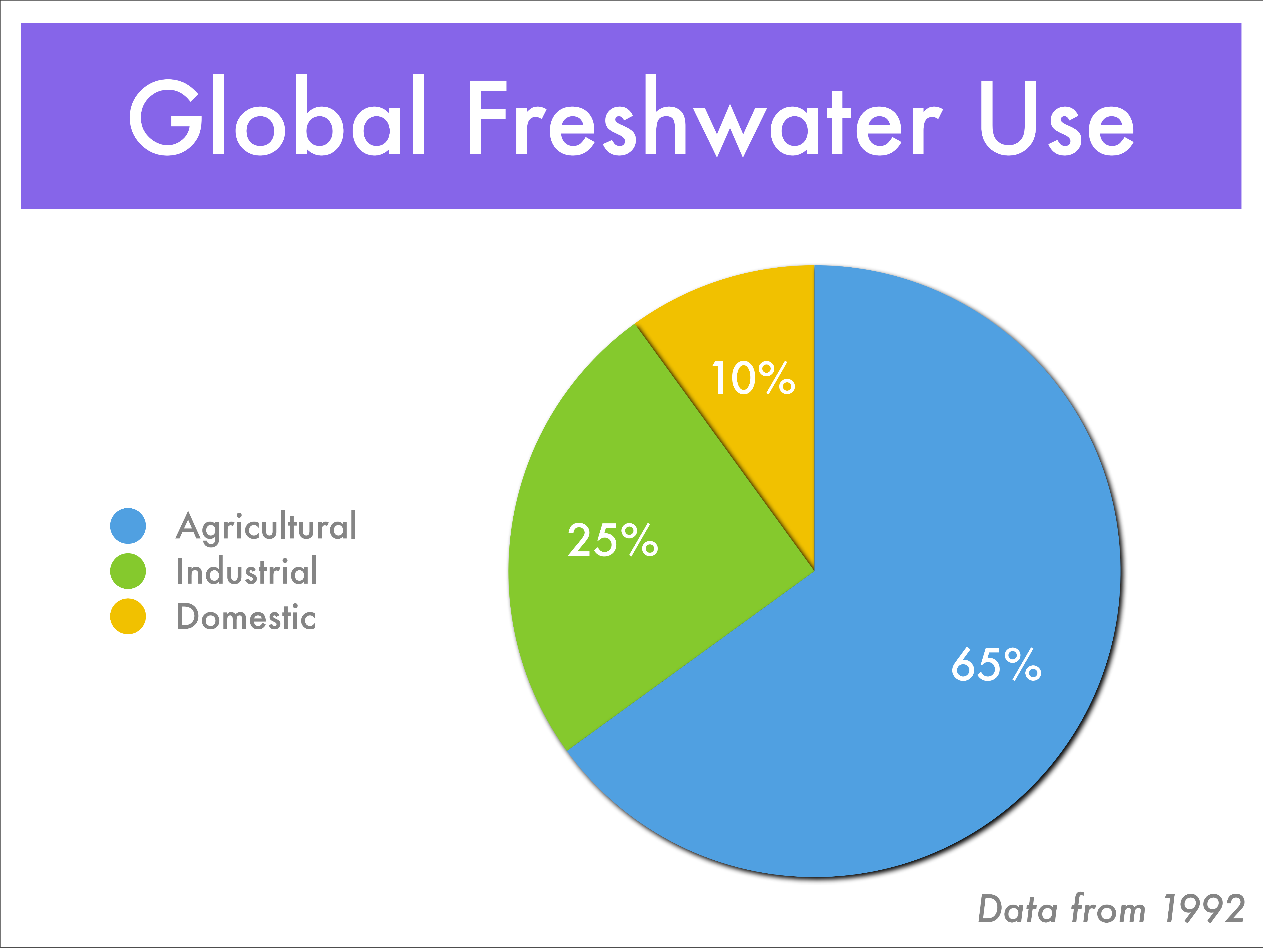
"…desalination holds out the unrealistic hope of a supply-side solution, which delays the onset of the water efficiency revolution so urgently needed."

Postel, Sandra (1992) "The Last Oasis: Facing Water Scarcity" Earthscan, London, pp45-7

Increasing Global Use



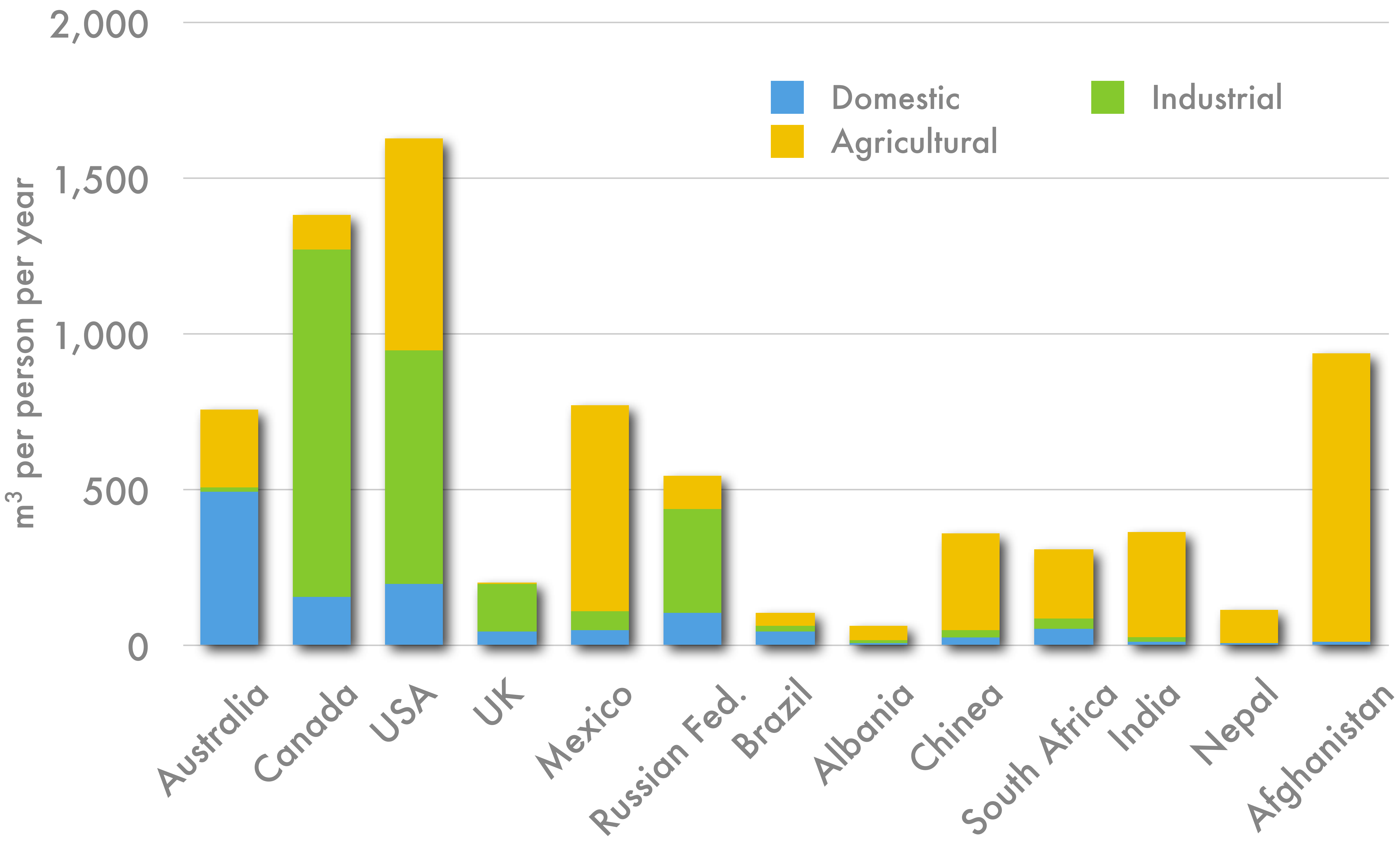
"During the last 50 years water use worldwide has grown fourfold" now accounting for roughly 10% of total river and groundwater flow from land to sea globally.
Houghton, John (1997) "Global Warming: The Complete Briefing" Cambridge University Press, p117



Statistics taken from “The Last Oasis: Facing water Scarcity” by Sandra Postel, 1992. pp19-20

Similarly, Houghton states that “Two-thirds of human water use is currently for agriculture, much of it for irrigation; about a quarter is used by industry; only 10 per cent or so is used domestically”
Houghton, John (1997) “Global Warming: The Complete Briefing” Cambridge University Press

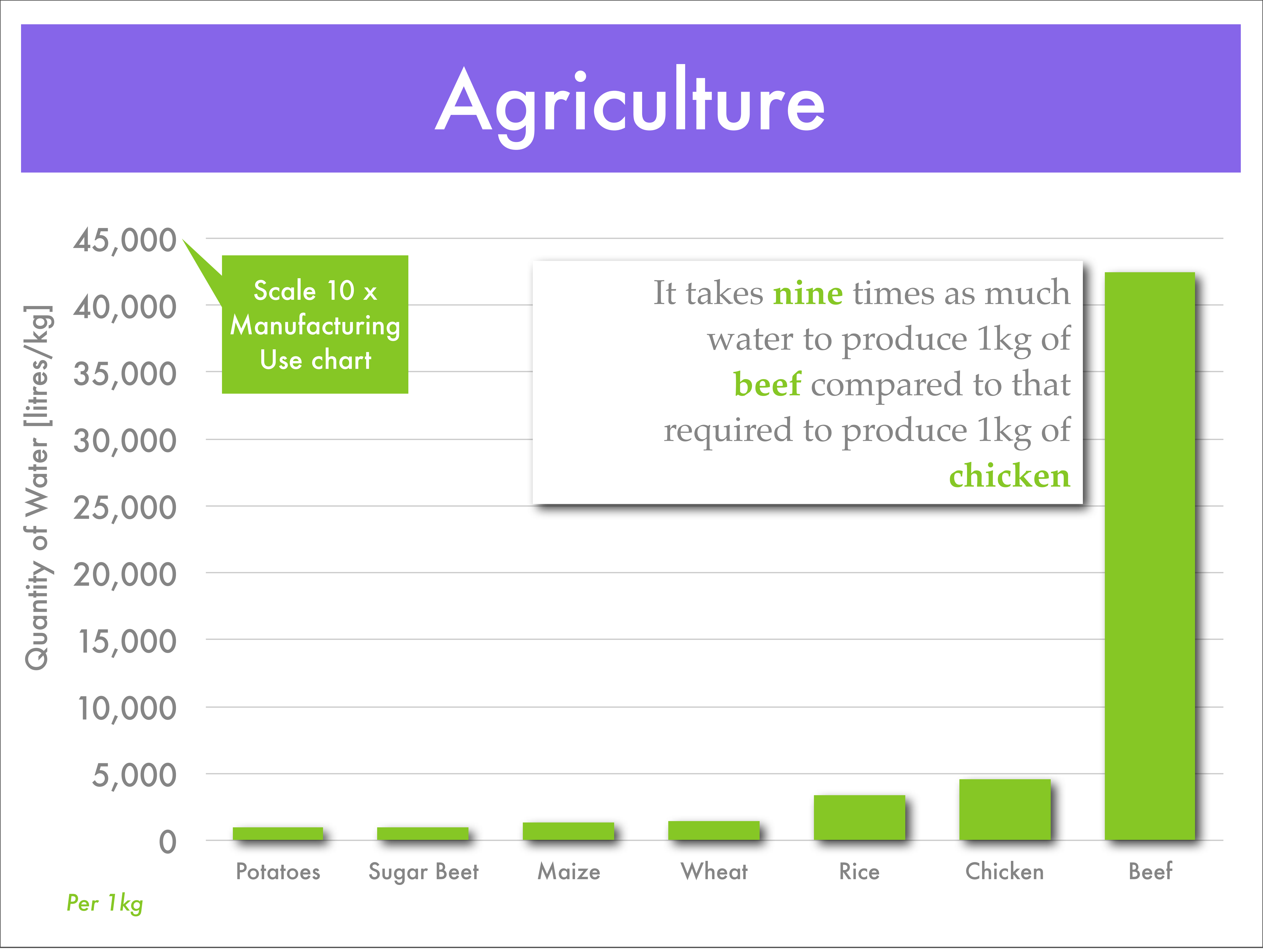
Water Use



Of the freshwater that is withdrawn for human use:
In the industrial world, the bulk of water is used for industry
In developing countries the bulk is used for agriculture, in places like Afghanistan and Nepal, this is 99%
In all countries, domestic use is a small, but important part

Data taken from Gleick, Peter (2003) “The World’s Water: The Biennial Report on Freshwater Resources” Island Press, pp245-251, Table 2: Freshwater Withdrawals, by Country and Sector (2002 Update)

Countries arranged in descending order of Human Development Index rank as taken from United Nations Development Programme (2005) “The Human Development Report – International Co-operation at a Crossroads: Aid, trade and security in an unequal world” Oxford University Press, Oxford and New York



As the human population increases, there is growing concern that there won't be sufficient water to grow the food required.
Meat takes much more water to produce than cereals:

Beef	15,000 to 70,000 litres per kg
Chicken	3,000 to 6,000 litres per kg
1kg rice	4500 litres per kg
1kg wheat	1000 litres per kg
1kg sugar beet	1000 litres per kg
1kg potatoes	550 litres per kg

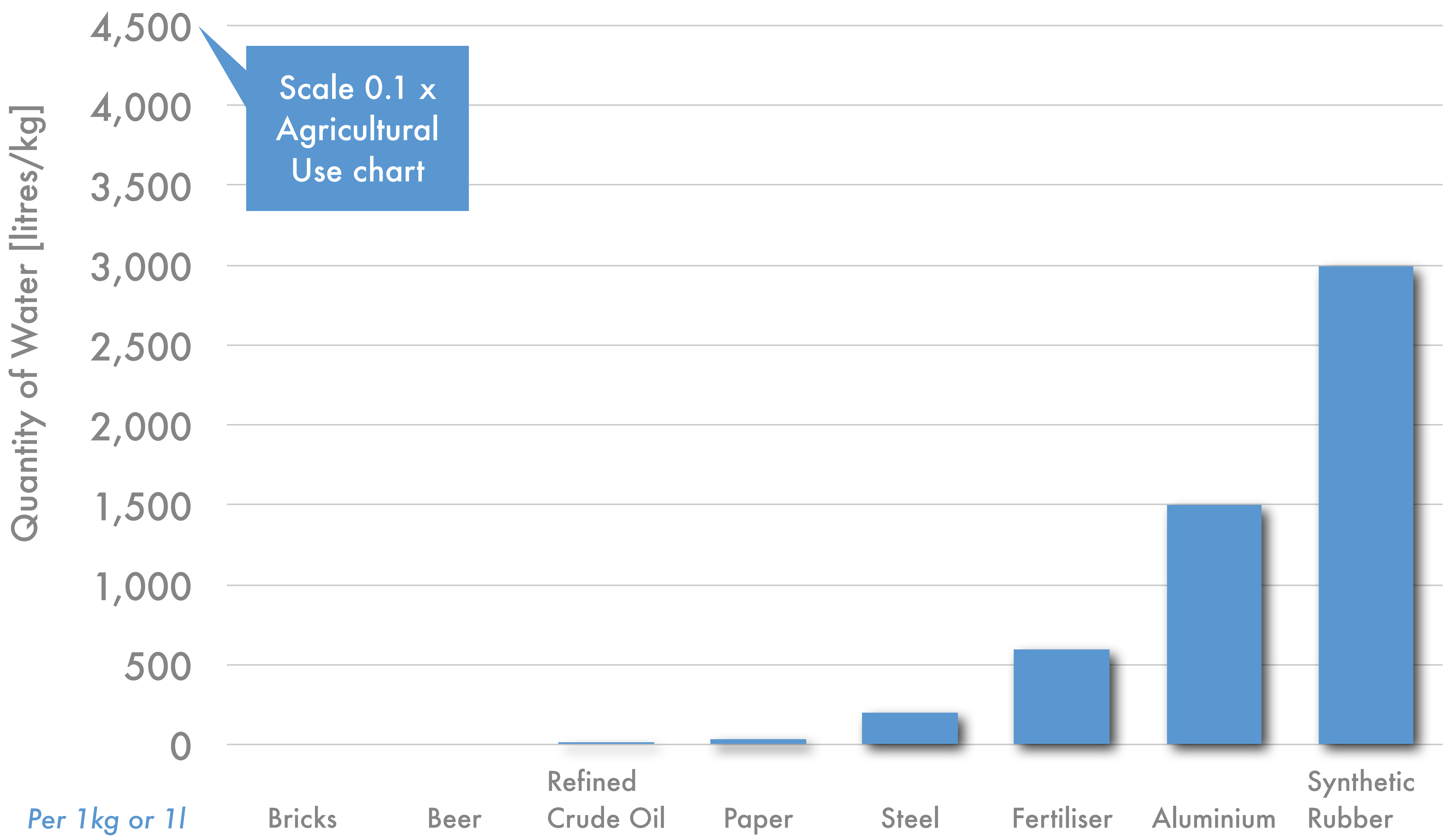
Data source: Open University (1995) "S268: Physical Resources and Environment" Block 3, pp6

Figures for meat - pork and chicken taken from Brown, Lester & Halweil, Brian (1998) "China's Water Shortage Could Shake World Food Security" World Watch, July/August 1998, pp10-21

Reflecting the true ecological cost of food "1 serving of hamburger, fries and soda requires 7000 litres of water to produce it"
Hawken, Paul; Lovins, Amory B. & Lovins, L. Hunter (1999). "Natural Capitalism – The New Industrial Revolution" Earthscan, London, pp339 note 20 – data from Prof. Jackie Giuliani of Antioch University (Los Angeles)

However:
In peak years of wheat grain production in Saudi Arabia (1994 – 5million tonnes) water deficit of 17 bcm and used 3000 tonnes of water to produce 1 tonne of wheat grain.
Sandra Postel, World Watch article, "When the World's Wells Run Dry", Sept.Oct.1999
Postel, Sandra (1999) "When the World's Wells Run Dry" World Watch, Sept/Oct 1999

Manufacturing



Manufacturing processes of various types often require large amounts of water. In many cases these processes were developed at a time when water scarcity was less realised than it now is. Water conservation measures taken by industry can be improved with the development of new equipment and processes that require less water.

Manufacturing:

1 litre beer	8 litres of water
1kg paper	15-40
1kg bricks	1-2
1kg steel	5-200
1kg aluminium	1500
1kg fertiliser	600
1kg refined crude oil	15
1kg synthetic rubber	3000

Data source: Open University (1995) “Physical Resources and Environment” Block 3, pp6

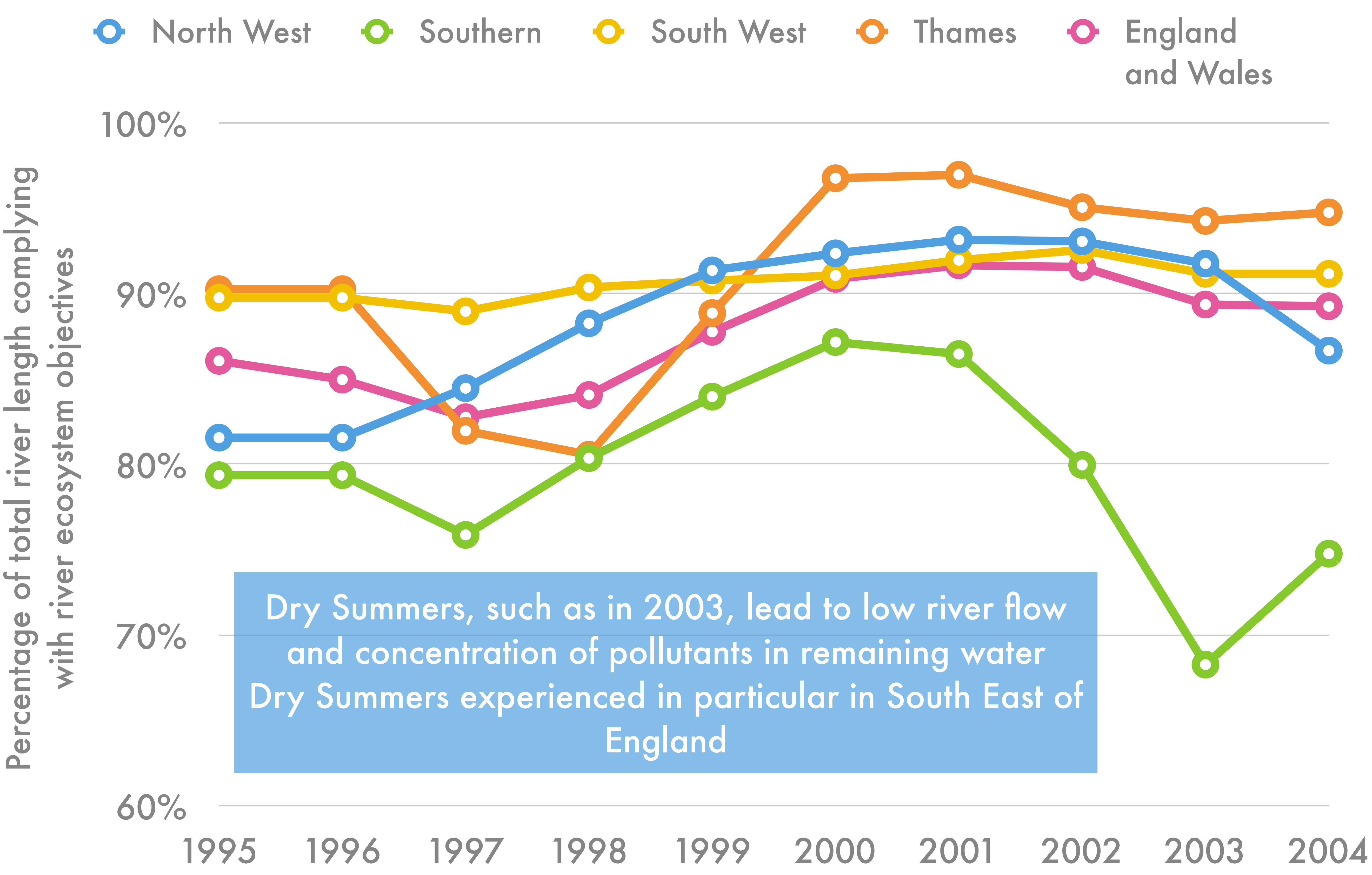
Much additional water is used in the process of manufacture for non-invasive processes such as cooling. While this does not necessarily greatly reduce river flow, if that is the source, it can result in changes to the river’s ecological system. Downstream of a warm water discharge, the change in river water temperature may encourage growth of algal blooms which can suffocate other flora and fauna inhabitants.

State of Rivers

In 1962 US Biologist Rachel Carson published her groundbreaking book “Silent Spring” which initiated an awakening about the impact of human activities as never really considered before.
Carson, Rachel (1962) “Silent Spring” Penguin, London

Prior to this revolutionary thinking the widespread understanding and practice had been that the earth and its systems are so vast that human activity could have no lasting impact on them. As such waste was dealt with by applying the “dilute and disperse” philosophy whereby waste (solid, liquid or gaseous) was released to the environment continuously, but in small unit quantities. The idea was that the environmental systems would be able to process this waste if it was sufficiently diffuse.

State of UK Rivers



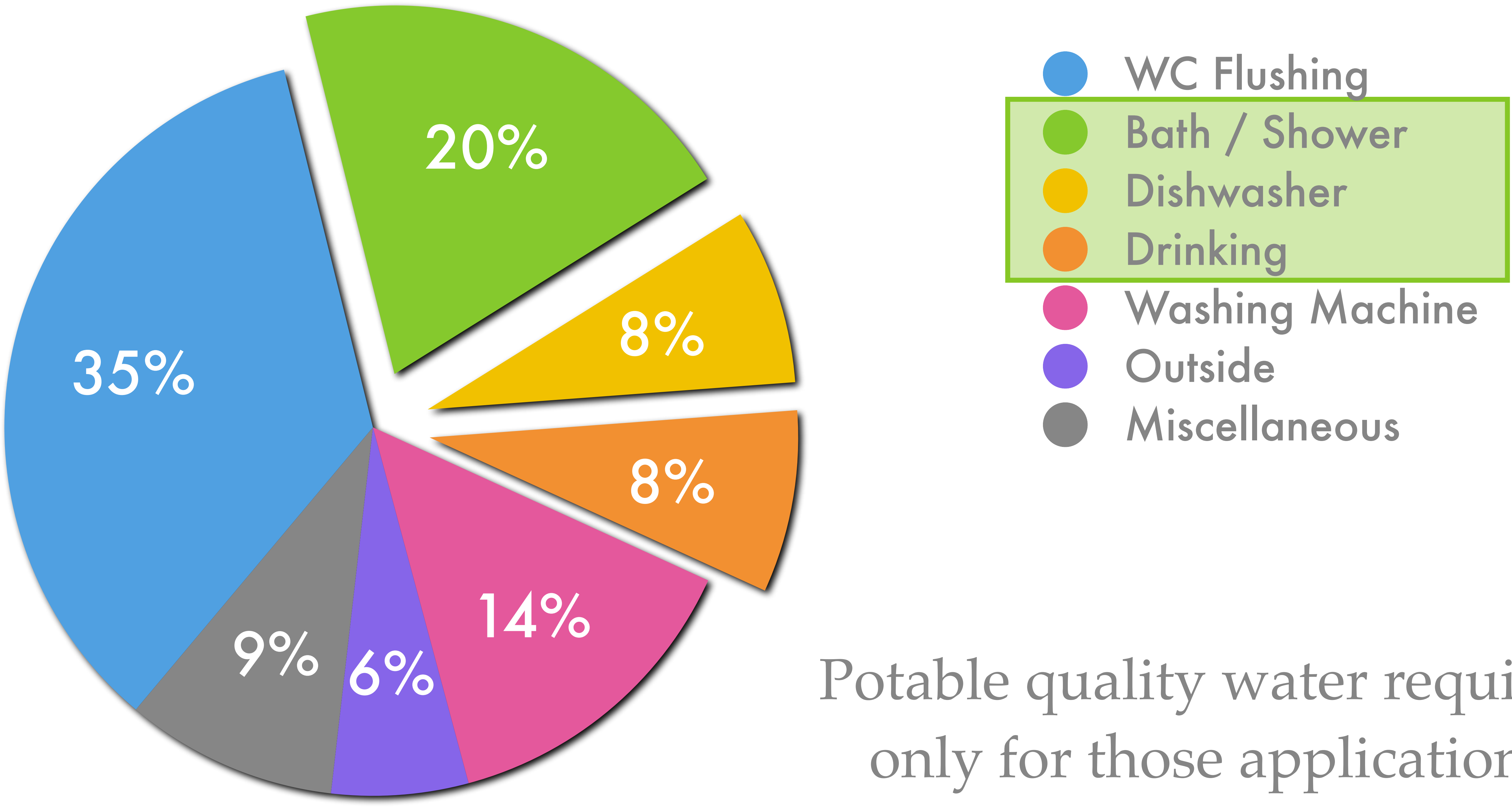
Rivers are a major source of drinking water and support a range of wildlife. They are used for many recreational activities and supply water to industry. River Quality Objectives (RQOs) provide targets to help protect and improve the quality of water in our rivers.

Despite a drop in compliance in 1997 and 1998 because of low river flows, there has been a substantial improvement in compliance with river quality objectives since 1995. The target for 2006 appears to have been met already but we cannot guarantee that this will be maintained until all planned improvements have been delivered, for example improvements to the sewerage system.

The increase in compliance is due to a number of factors including a major clean-up of discharges from sewage-treatment works and industry. Between 1990 and 2000 industry invested large amounts of money in environmental programmes. For example, water companies spent over £4 billion on improving discharges to inland waters. In the five years to 2005, they will spend a further £2.9 billion. In addition the Environment Agency continues to prosecute illegal dischargers and enforce compliance with discharge consents.

Data for graph from Environment Agency (2005) “River Quality Compliance Data 1995-2004” available at http://www.environment-agency.gov.uk/commondata/103601/i5_gqa_wa5_dta_461389.xls

UK domestic water use



Potable quality water required only for those applications indicated – approximately one third of total domestic use

Although domestic water use accounts for only a small fraction of the total, it is concentrated in urban areas where it may cause local problems. There are many ways in which domestic water use could be reduced at relatively small cost.Water pricing policies will become increasingly important. Public perception of water is based on price and availability.

UK Domestic Water Use:

Flushing lavatory, per flush	6-22 litres
Bath	80-170 litres
Shower, per minute	5-10 litres
Automatic washing machine, per load	70-110 litres
Dishwasher load	55 litres
Watering garden for 1 hour	1000-1300 litres

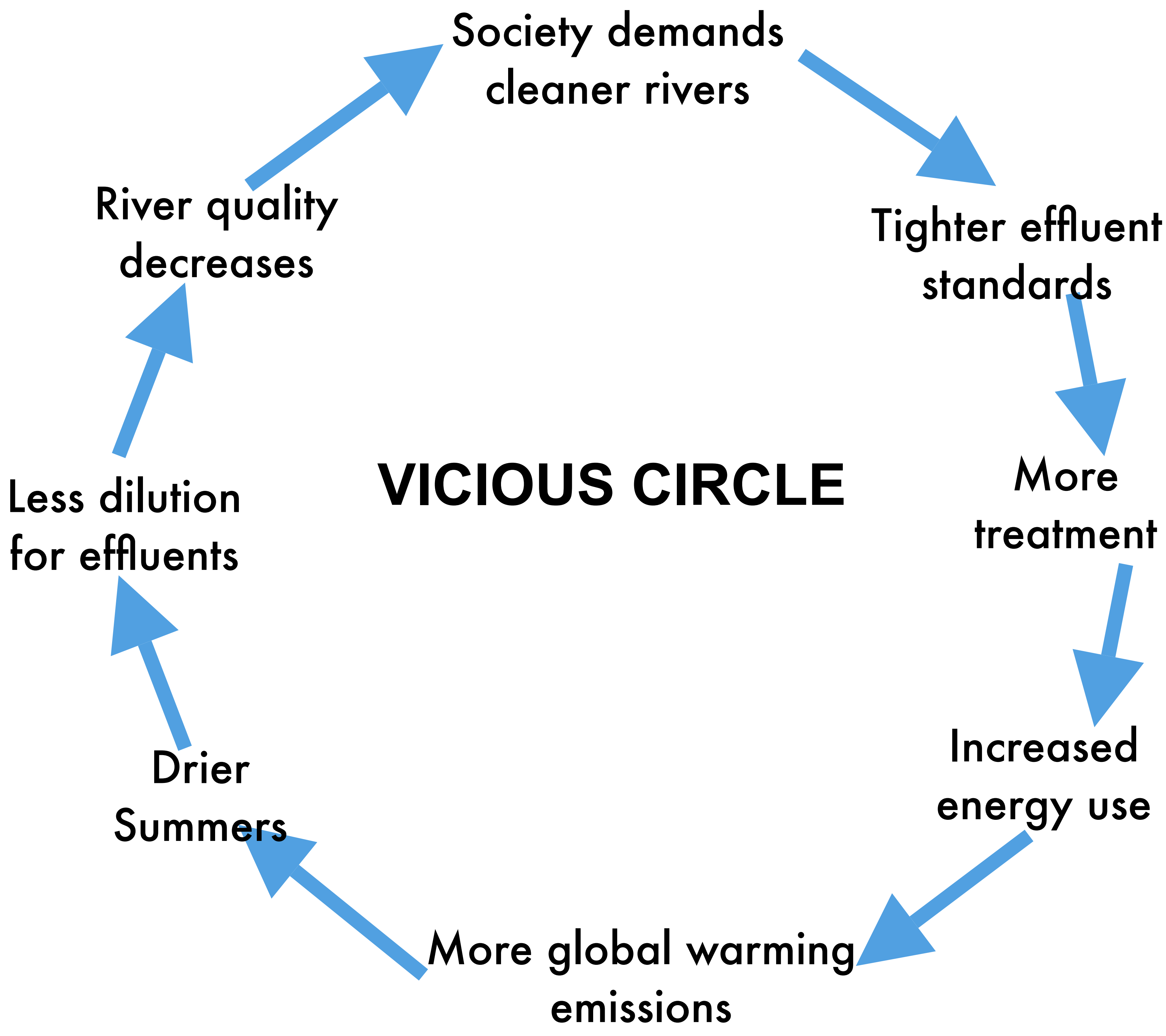
Data source: Open University (1995) “Physical Resources and Environment” Block 3, pp6

All water that is piped into homes in the UK is treated to very high EU quality standards. Much of the water we use domestically is consumed in non-potable uses such as gardening and flushing toilets. Only uses including drinking, cooking and for baths and showers need to be potable for health reasons. These uses account for only around one third of total supply.

Data Source: Environment Agency 2001 “Conserving water in Buildings (September 2001)” Water Resources available at http://www.environment-agency.gov.uk/subjects/waterres/286587/286599/286911/548861/?version=1&lang=_e

Energy costs of stricter water treatment legislation

- Water Industry and Global Water
- The Paradox of treating all water to a fully potable standard



In their 2001 Annual report, Thames Water highlighted the problem of treating water to ever higher standards and the effect that the increased energy consumption has on climate change.
Thames Water (2001) “Environment and Conservation Review 2001” ,page 4 available at http://www.thames-water.com/en_gb/Downloads/PDFs/environmental_review_2001.pdf

The water sector is identified as the third most energy intensive sector in the UK according to the Marshall report on energy use in UK
Marshall, Lord (1998) “Economic Instruments and the Business Use of Energy” HM Treasury, November 1998

Flooding

Early Settlements

Built on high ground above rivers
Key buildings such as churches protected from flooding

Recent Developments

Expansion onto flood plain
Key buildings such as **hospitals** at risk of flooding

Population growth and increasing urbanisation, coupled with paving over of more land leads to less surface water infiltration, higher peak flow after storms and increased frequency and severity of flood events

Flooding is another water related problem that is increasing as population grows and urban areas expand. Many riverside settlements have encroached onto the protective flood plains.
Early settlements were built on hills above rivers. The locally elevated areas where higher ground abuts the river channel were populated so that the inhabitants could benefit from proximity to a water supply, but be protected in times of flood. In old towns the significant historical buildings, such as churches, can often be found on the highest ground, with residential buildings all around, often the wealthiest nearest the top and the poorest nearest the river.
Recent developments have been forced to utilise available land on the outskirts of the old town. This has often resulted in significant buildings such as hospitals, schools and factories being located on the flood plain and at significant risk. This encroachment onto the natural flood channel of rivers has led to significant challenges.
Institution of Civil Engineers (2001) "Learning to Live With Rivers: Final Report of the Institution of Civil Engineers' Presidential Commission to Review the Technical Aspects of Flood Risk Management in England and Wales" Institution of Civil Engineers, London, November 2001 available at http://www.ice.org.uk/rtfpdf/iceflooding.pdf

Dublin Principles

Principle No. 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.

Principle No. 2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.

Principle No. 3: Women play a central part in the provision, management and safeguarding of water.

Principle No. 4: Water has an economic value in all its competing uses and should be recognised as an economic good.

International Conference on Water and the Environment

Principle No. 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment. Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or ground water aquifer.

Principle No. 2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels. The participatory approach involves raising awareness of the importance of water among policy-makers and the general public. It means that decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

Principle No. 3: Women play a central part in the provision, management and safeguarding of water. This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

Principle No. 4: Water has an economic value in all its competing uses and should be recognised as an economic good. Within this principle, it is vital to recognise first the basic right of all human beings to have access to clean water and sanitation at an affordable price. Past failure to recognise the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.

(ICWE 1992)

In 1992 the International Conference on Water and the Environment was held in Dublin, Ireland. The output from this conference was a declaration regarding water that was presented to the United Nations Conference on Environment and Development (UNCED) that was held in Rio de Janeiro in June that year where the ideas from the 1987 UN Report (the Brundtland Report), were discussed and developed. The Rio conference, which came to be known as the "Earth Summit", was attended by one-hundred-and-eighteen heads of government and was the major turning point in bringing the issues of sustainability and sustainable development onto the international political stage. The inclusion of the Dublin Principles in the conference debate helped to highlight the importance of water as a resource for environmental protection and human development.

The Dublin Principles remain the standard for consideration of the issues surrounding water resource use and protection.

Declaration of the International Conference on Water and the Environment, Dublin, Ireland, 26th-31st January 1992 available at http://www.wmo.ch/web/homs/documents/english/icwedece.html

Hydropolitics

Control of Water Resources: Water supplies or access to water at the root of tensions

Military Tool: Water resources, or water systems themselves, used by a nation or state as a weapon during military action

Political Tool: Water resources, or water systems themselves, used by a nation, state or non-state actors for a political goal

Terrorism: Water resources, or water systems, as targets or tools of violence or coercion by non-state actor

Military Target: Water resource systems as targets of military actions by nations or states

Development Disputes: Water resources or systems as source of contention in the context of social and economic development

We are facing a global water shortage that is linked to our food supply. There are a number of other ways in which water supply may affect world politics. Conflict events often fall under several categories of definition as shown in the slide. These could form the basis of discussion topics.

Definitions from: Gleick, Peter (2001) “The World’s Water: The Biennial Report on Freshwater Resources” Island Press, pp182-3

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