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

Updated and modified by Dr Heather Cruickshank and Dr. Sue Jackson, ImpEE Project, Department of Engineering, University of Cambridge

version 3

February 20th, 2006
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” From 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)  

Annually, around 505,000 km$^3$ is evaporated from the oceans, and 72,000 km$^3$/year is evaporated from land surfaces to join the hydrological cycle. This gives a total of around 577,000 km$^3$/year active in the global water cycle. Of this total, approximately 458,000 km$^3$/year (80%) falls back onto the oceans and only 20% (119,000 km$^3$/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, 7000 km$^3$ more water is stored on land in March than in September when 600 km$^3$ more is stored in the atmosphere than in March.


A good explanation of the hydrological cycle can be found at: http://www.groundwateruk.org/html/forum/forum.htm
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’.


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.’

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. 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.

For general human health requirements, volumes required are as follow:

<table>
<thead>
<tr>
<th>Category</th>
<th>Volume Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>50 litres per person per day</td>
</tr>
<tr>
<td>Emergency</td>
<td>Sphere guidelines 15 litres per person per day</td>
</tr>
</tbody>
</table>

Some of the most water scarce countries are small island nations such as Malta (50m³/capita/year) and the Maldives (105m³/capita/year), Singapore (144m³/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 700m3/year giving a total human use of 3850 km3/year. Now the world use of water is about 6000 km3/year, which is a significant fraction of the naturally available fresh water.

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


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 0.02 km³/year and an annual freshwater withdrawal of around 0.54 km³/year (2700% of available renewable supply). Saudi Arabia extracts the greatest volume of water (14.62 km³/year) beyond it’s renewable supply (2.4 km³/year) and uses 7 times more than it has available, but UAE (1.91 km³/year debt and consumption 10 times renewable supply) and Libya (4 km³/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 50.4 km³/year renewable available freshwater, but withdraws around 58.05 km³/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 level must be reduced to 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.
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.


“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 revolutionary so urgently needed.”

"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
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.”

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
- **1 kg rice:** 4,500 litres per kg
- **1 kg wheat:** 1,000 litres per kg
- **1 kg sugar beet:** 1,000 litres per kg
- **1 kg potatoes:** 550 litres per kg


Reflecting the true ecological cost of food: “1 serving of hamburger, fries and soda requires 7000 litres of water to produce it”


However:

In peak years of wheat grain production in Saudi Arabia (1994 – 5 million 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


It takes **nine** times as much water to produce 1kg of **beef** compared to that required to produce 1kg of **chicken**.
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
- 1 kg paper: 15-40
- 1 kg bricks: 1-2
- 1 kg steel: 5-200
- 1 kg aluminium: 1500
- 1 kg fertiliser: 600
- 1 kg refined crude oil: 15
- 1 kg 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.

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 in sufficiently diffuse.
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.

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


All water that is piped into homes in the UK is treated to very high EU quality standards; however, 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.

Energy costs of stricter water treatment legislation

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

Society demands cleaner rivers

River quality decreases

Less dilution for effluents

Drier Summers

More global warming emissions

Tighter effluent standards

More treatment

Increased energy use

VICIOUS CIRCLE


Flooding

**Recent Developments**

Expansion onto flood plain

Key buildings such as hospitals at risk of flooding

**Early Settlements**

Built on high ground above rivers

Key buildings such as churches protected from 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.

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.
**Hydropolitics**

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

**Control of Water Resources:** Water resources, or water systems themselves, used by a nation or state as a weapon during military action

**Control of Water Resources:** Water resources, or water systems themselves, used by a nation, state or non-state actors for a political goal

**Control of Water Resources:** 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

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.  
ImpEE is based at the Department of Engineering at the University of Cambridge and is funded by the CMI Institute.

© University of Cambridge, 2006

This material was produced as a part of the ImpEE Project at the University of Cambridge. It may be reproduced, modified and used freely for educational purposes.

UNIVERSITY OF CAMBRIDGE

ImpEE is based at the Department of Engineering at the University of Cambridge and is funded by the CMI Institute.