Engineering the future

Global Water Security – an engineering perspective

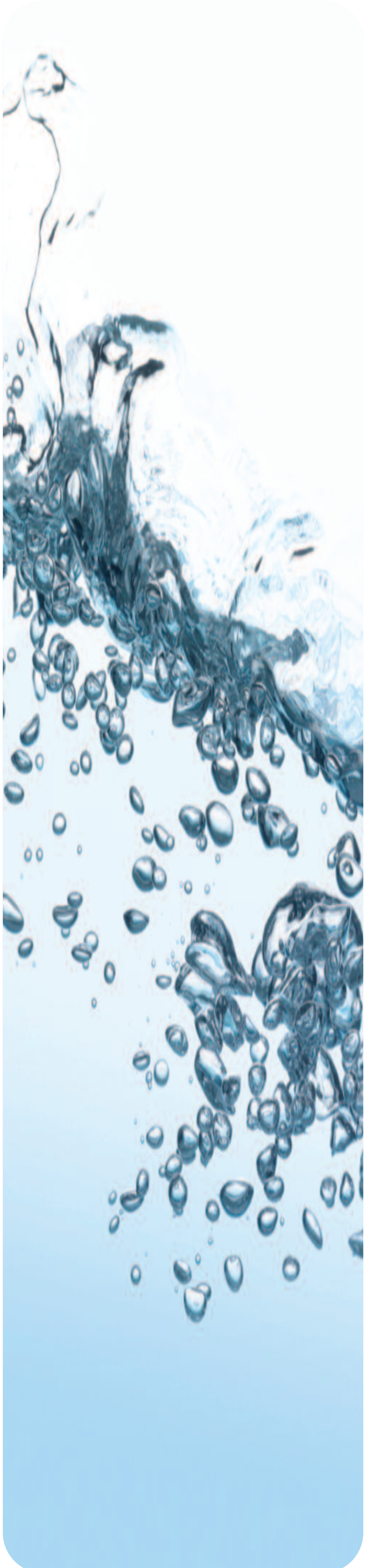
Global Water Security –
an engineering perspective

ISBN 1-903496-55-1

April 2010
Published by
The Royal Academy of Engineering
3 Carlton House Terrace
London SW1Y 5DG

Tel: 020 7766 0600   Fax: 020 7930 1549
www.raeng.org.uk
Registered Charity Number: 293074

A copy of this report is available online at
www.raeng.org.uk/gws



Contents

Foreword by Professor Peter Guthrie OBE FICE FREng Chair of the Steering Group on Global Water Security

"Getting to grips with the threats to water security is not straightforward and requires innovative and dedicated approaches. Possible responses include increasing supply, managing demand and allocating water differently. This report sets out to approach the issues surrounding water security systematically. It argues that there needs to be a review of the governance and regulation of water so that the technologies that exist can be used effectively and efficiently and the need for new technologies can be identified."

We face daunting challenges. The 'perfect storm' scenario[1] suggests that by 2030 the world will need to produce 50 per cent more food and energy, together with using 30 per cent more fresh water, whilst mitigating the causes of, and adapting to climate change. There is no single 'silver bullet' that can be adopted or applied to resolve the issues surrounding global water security; however, technologies and expertise that can aid us in confronting these problems already exist. What is required is the implementation of effective governance, financing and regulation, to allow technical solutions to take effect.

Engineers have the skills and technologies to develop effective solutions to many of the problems that surround global water security. In isolation these technologies and skills are not enough. It is incumbent on engineers to articulate the issues surrounding water security to those outside of their usual sphere. Engineers must engage with policy makers, economists, financiers, farmers, industry and development agencies in order to build the public-political consensus needed to approach the problem of global water security.

The implementation by governments and public authorities of policies and strategic responses to water scarcity problems rely for their success on a positive response from individuals and communities. Existing values, cultural norms and organisational structures that either empower or disenfranchise individual citizens determine patterns of individual behaviour and organisational response. Individual and institutional inertia may be difficult to overcome without raising awareness and understanding of the key issues and potential responses and making sure that these are firmly included in the broader public debate on sustainable resource use and management.

This report addresses water security as a global issue as well as considering the situation of the UK in that context.

On behalf of the Steering Group, I would like to thank all of those who have contributed evidence to the inquiry from which this report is generated. It is our hope that this report can be the first step in a process that will highlight the significant problems surrounding global water security, bring together those who can help approach these obstacles and, mobilize the technology, techniques, skills and research that can aid us in the resolution of these issues.

Executive summary

Background

1. Water underpins the very fabric of human life – our food and drink, the clothes we wear, the landscapes we enjoy, the societies we live in, the length and quality of our lives. The essential role that water plays in national life – in energy supply, infrastructure, economic growth, healthcare, education and culture – makes water a central concern for national policies. Because the water cycle is global, the availability, use and security of water transcend local, national and even continental boundaries.

2. Water security is under severe pressure from many sources; a world population explosion, rapid shifts of people from rural to urban areas, the impact of dietary change as countries develop, increasing pollution of water resources, the over-abstraction of groundwater and the not insignificant issues created by climate change.

3. The world is far from water secure. In many parts of the world the demand for water is already much greater than the available supply. This is not an issue that affects only developing countries, where water infrastructure is poor and where many people do not have access to safe drinking water, but also the developed world, where burgeoning demand simply cannot continue to be met. Water for agriculture and, therefore, food is not given sufficient attention on the global stage, where water supply and sanitation issues currently dominate. In order to move water for agriculture up the agenda on the global scene, water engineers, farmers, economists and policy makers will need to improve their communications with one another.

4. Water has traditionally been regarded as a free resource. Any costs for water are usually associated with the cost of processing and delivery alone, rather than assigning any inherent value to the resource. There is growing interest internationally in the use of water pricing to reduce demand as well as to generate revenue to cover the cost of providing water supplies and maintaining infrastructure.

Findings

The need for a systems based approach

5. Water management solutions should be considered in the context of the entire water system, from 'cloud to coast' as well as the implications immediately upstream and downstream. In this systems approach, all types of water must be considered together and in this context, the flows and uses of water in a catchment area feeding the soil (green water), free water in rivers and reservoirs (blue water) and used or waste water (grey water) all need to be included. Such an approach can lead to significant efficiencies in managing water systems.

Issues of policy and governance

6. The impact of policy in one nation can have impact on the water security of other nations. There is a need for governance at all scales – global, regional, national, local, as well as at the catchment level and a

need for linkages between these scales. In situations where rivers cross national boundaries or lakes are shared between countries, trans-boundary agreements for water allocation and sharing may be enshrined within international treaties. Tackling threats to global water security requires responses tailored to the individual country's political, social, economic, environmental, financial and cultural conditions, and will, in most cases, require international coordination.

7. Developed nations are in a position to meet some of their water needs by importing 'virtual' water in the form of goods and services from other countries. The UK is reliant on food, energy and goods that require water in their production and transportation by and from countries that are themselves under water stress. This hidden water accounts for over 2/3 of the UK's water footprint. Government must assess the interrelationship between water, food and energy security in UK with a view to achieving an optimal balance of aligned national policy.

   The importance of water security to national security should be a core component of policy making. Water security should be considered as part of climate change mitigation and adaptation policy and the global impacts on water security of our national and international policies need to be assessed. The technologies, practices and management approaches that will be required to address water security issues must be identified and supported through research and development. Government should review the needs for public engagement, education and awareness-raising around the subject of water security.

   Given the impending worsening of water security, particularly in some developing countries, the UK Government should put water at the centre of its international development policy. There should be recognition that infrastructure development is of no use on its own, unless the institutional capacity is developed in-country and all levels of stakeholders are engaged to make it work.

8. Improvements in climate modelling are crucial to help predict the temporal and spatial distribution of the effects of water scarcity. As well as fulfilling their traditional role in designing and building water infrastructure and management systems, engineers and policy makers must engage with communities, with society and with industry about demand management, sustainability strategies and their impact on daily life.

   The UK professional engineering bodies have a role to play in helping embed awareness of the water security challenges among their global membership. The professional qualifications that the engineering institutions administer can ensure qualified engineers know and understand the appropriate technologies, legislative frameworks and latest best practice for taking a systems based approach to water security. Such organisations also have a role to play in coordinating dialogue with the public.

   The education and training of engineers needs to combine experience-led technical learning and systems thinking with elements on such issues as sustainability, ethical and societal dimensions of engineering and the impact of trade and transboundary conflicts.

Responsibility and regulation

9. Businesses can examine their supply chains and production processes

to assess and reduce their water footprint as a core component of their corporate social responsibility strategies. Their analysis should not be restricted to their home country but also to those regions from where they import goods, materials and services. A commitment to openness and transparency about the impact of business operation on water supplies in country will help create a 'stress map' that will support international policymaking. Business should be encouraged and incentivised to develop tools to support effective policy development and decision making to enable sustainable management of water resources.

10. The regulation of the water sector globally needs to be focused on integrated water resource management and sustainability. All too often there is little synergy between long term water resource management and the need to provide water and sanitation services. Indeed Governments often view the water sector as purely the utility operators and neglect the water resource, ecosystem and amenity functions. This is a common issue across the developed and developing world. For example in the UK the water utilities in England and Wales have been required, in the recently completed price review process, to produce a 25 year forward view by the regulator Ofwat. Whilst this is welcome, the regulator has focused in reality, only on the companies' investment plans over the next five year period.

    This disconnect is a problem and highlights the need to develop sustainable regulation for the water sector. In Europe, the EU Water Framework Directive, which concentrates of the health of aquatic ecosystems and their ecological quality, is being brought into force in all member states. The implementation of this directive will challenge existing regulatory systems to accommodate a more sustainable approach.

New knowledge and engagement

11. Changes in water consumption at an individual level will be crucial to tackling water scarcity. Achieving a significant reduction in demand represents a major challenge in raising awareness and changing customer attitudes. The choice to adopt technologies and practices to reduce consumption lies, to a certain extent, with the individual who needs to be encouraged or incentivised to change behaviours.

12. Many of the technologies, techniques and practices needed to address water security already exist but need to be refined, developed or improved. When considering the role of technology in providing new sources of water, it is important to be conscious of the effects that it can have on the ecosystem as a whole. UK research must rise to the challenges of developing and improving the new tools and technologies which will contribute to solving of water scarcity and delivering global water security. Examples include: water resource allocation and optimisation models, predictive climate change water scarcity impact models, the impact of climate change on water quality, development of new water policy, regulation and governance frameworks and development of innovative financing mechanisms for water infrastructure.

    New knowledge and sustainable technologies or practices that need to be developed include:

- management of existing sources to provide potential for the storage of excess flows during floods
- surface water storage by dams in line with the World Commission on Dams' (WCD)[2] five 'core values'
- sustainable use of groundwater and better understanding of aquifers
- water efficiency in agriculture through water management and drainage and improved surface irrigation alongside drought-heat tolerant crop varieties (in parallel with improvements in plant breeding or genetic manipulation to reduce irrigation demand)
- more water efficient industrial production processes
- better management of water supply and distribution systems
- development of new water sources and improving performance of existing sources
- desalination of seawater or brackish water including strategies for handling the concentrated brine waste streams
- better modelling of water systems with improved monitoring, data collection and validation.

Recommendations

1. Inter-governmental bodies such as the WTO, and key discussion fora such as the UNFCCC must elevate the issues of water security in their strategies. Water footprints and virtual water content of globally traded goods and agricultural products need to be taken into account in trade negotiations to protect communities suffering from water stress.

2. Water security should become a core component of UK policy making. Government must assess the interrelationship between water, food and energy security in UK, informed by a systems based approach, with a view to achieving an optimal balance of aligned national policy.

3. UK industry must show leadership on global water security. Through their global reach, businesses must examine their supply chains and production processes to assess and reduce their water footprint. This should be a core component of their corporate and social responsibility strategies.

4. The regulation of the water sector globally needs to have integrated water resource management and sustainability informed by a systems approach at its core. The current disconnect between the provision of water and sanitation services and the wider water resource issues are all too apparent and it is essential to change the way the water sector is viewed and regulated.

5. The Government should bolster investment in the research and development of solutions to global water security and work with the UK water industry to improve the development of the necessary models and data collection techniques to underpin international development policy.

6. The UK engineering institutions should ensure that their global memberships are appropriately equipped, through professional development, to apply a systems led approach to water engineering, incorporating the technical, geo-political, societal and ethical dimensions of the challenge. Engineers, along with all agencies involved need to engage with stakeholders to promote systems based solutions and with the public in general to support informed decision making in connection with water use.

1. Introduction, scope and definitions

In the simplest terms, water stress occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. A March 2010 report by World Bank's Independent Evaluation Group found that the effects of water shortages are felt strongly by 700 Million people in 43 countries. In this report we use the widely accepted figure of an annual supply below 1700m^3 per person to define water stress.

The report also looks at the management of water resources in the context of the whole water cycle, a naturally occurring sequence in which water moves through various physical states and transformations. In this cycle 'blue water', which accounts for approximately 40% of total rainfall, establishes itself in lakes, rivers and aquifers. Around 60% of total rainfall, 'green water', does not reach these destinations and is directly absorbed into the soil.

This often results in green water being disregarded as part of water resource management. However it has a vital role in maintaining delicate ecosystems and providing water for agriculture. Agriculture accounts for 70% of all water use (and in some countries over 90%), therefore improved management of resources in this area is vital for any effort to improve global water security.

Finally, we also consider 'grey water', water that has been used once but can be used again for another purpose. This can also be a significant resource; however, care must be taken that the water is suitable for the designated second use.

This study has been undertaken on behalf of *Engineering the future*, an alliance of professional engineering organisations, by the Institution of Civil Engineers, the Chartered Institution of Water and Environmental Management and the Royal Academy of Engineering.

The study group (see Annex A) gathered both oral and written evidence from practising engineers, engineering managers and consultants, academics, economists, service providers, water managers and government officials. The evidence collected has helped build a broad understanding of the issues that affect global water security and has helped the steering group produce an assessment of how these problems can be approached.

Water underpins the very fabric of human life; the food and drink we consume, the societies we live in, the length and quality of our lifespan. Maintaining and ensuring the security of water and the ability to supply demands from the water resources available, is essential to humankind. Freshwater is a natural resource which, through the hydrological cycle, benefits from a replacement process. However, it is only a very small proportion of the total water available on the earth. It also suffers from intense competing demands and has no surrogate.

Water security has different implications and connotations depending on where in the world one lives. For everyone however, water is fundamental to being able to live a healthy and productive life whilst maintaining the natural environment. It is a sobering reality that, in many places, water is a scarce and contaminated resource. Over one billion people have no access to clean drinking water; about one third of the world's population lack satisfactory sanitation. [3]

The fundamental role that water plays in food security, energy security, economic growth, maintaining health and reducing poverty, means there is a constant and ever increasing pressure on it as a natural resource. With global population growth estimated to increase from 6.8 billion today to 8 billion by 2025[4] and, alongside other drivers such as the potentially damaging effects of climate change, the demand on water resources is becoming ever more unsustainable in relation to supply.

Although water is only explicitly mentioned in one of the Millennium Development Goals, it is implicit in the achievement of each of them.[5] The responsibility for water security does not rest with one group or institution: It is a multi-level issue in which many people have a duty to participate. The current approach from many institutions and nations is fragmented. The commonality of water must be recognised and utilised to improve cooperation in all aspects of water resource management.

2. Managing the water cycle

The hydrological cycle is a naturally occurring sequence in which water moves through various physical states and transformations. The effects of human intervention on any part of the water cycle have the potential to impact on the whole. Water resource management therefore needs to be approached from a systems level perspective that includes the whole of the water cycle and the human, economic and environmental systems that depend on it, rather than merely focusing on individual components.

Blue water, which accounts for approximately 40% of total rainfall, is the part of the water cycle that establishes itself in lakes, rivers and aquifers. Around 60% of total rainfall, green water, does not reach these destinations and is directly absorbed into the soil.[6] This often results in green water being disregarded as part of water resource management. Its vital role in maintaining delicate ecosystems and providing water for agriculture means that it must be considered alongside blue water as a vital water resource. Grey water, water that has been used once but can be used again for another purpose, can also be a significant resource; however, care must be taken that the water is suitable for the designated second use. Grey water may be used without treatment, for example, to irrigate non-food crops or to flush toilets.

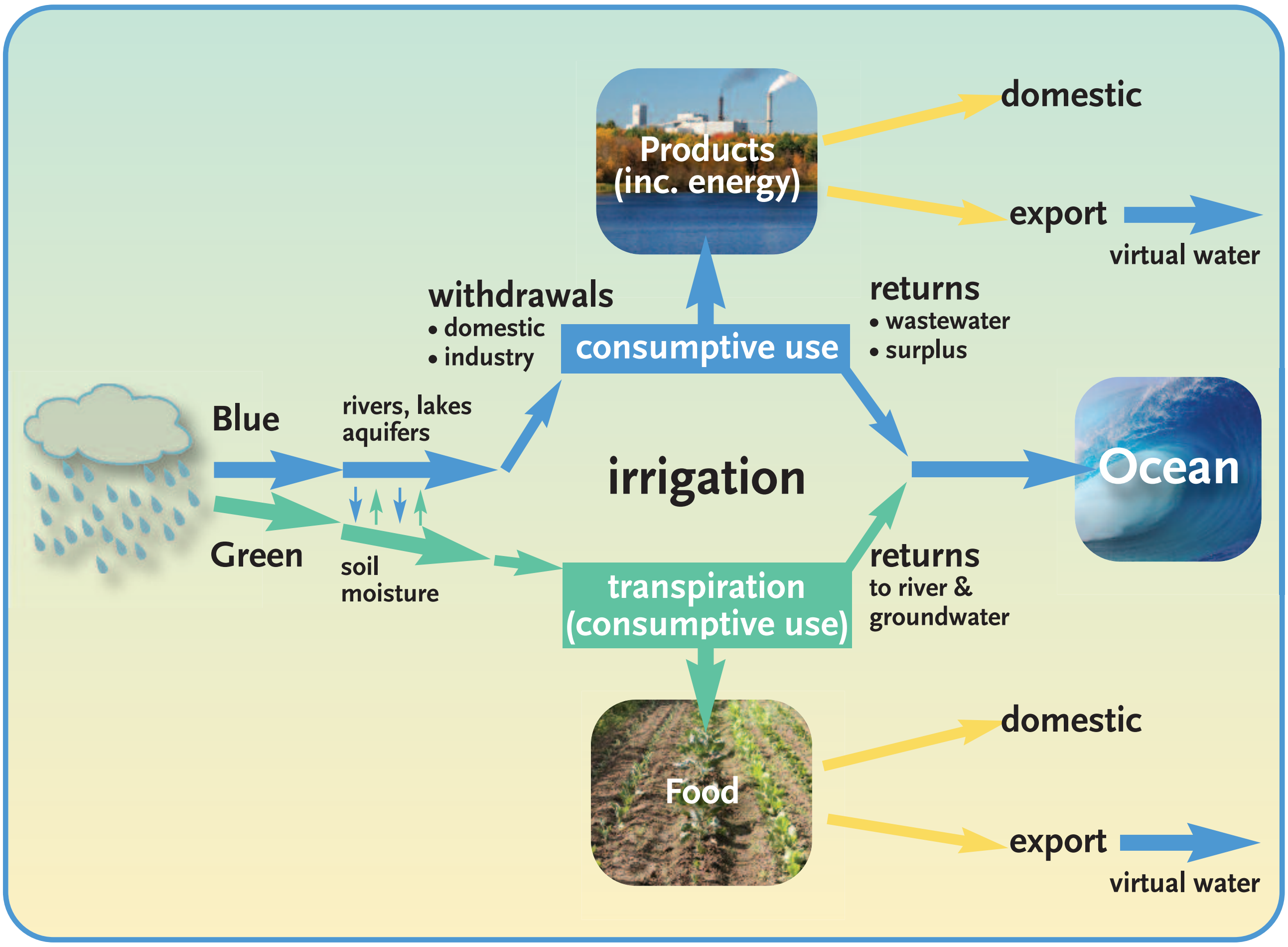


Figure 1 Water cycle diagram

It is also important to distinguish between 'consumptive' and 'non-consumptive' uses of water. Water abstracted and used for consumptive purposes is no longer available for use elsewhere in the water cycle. Non-consumptive use means that water is returned to the surface or groundwater systems once it has gone through a productive process, and can often be used again.

2.1 Causes of water stress

The world's freshwater resources are distributed unevenly, as is the world's population[7]. This means that water stress is unevenly distributed, as Figure 2 plots the current and predicted distribution of water stress.

Where water demand cannot be met by available water resources, an area is considered to be affected by *physical* water scarcity. Large areas of the southwest USA and much of the Middle East are examples of this kind of water stress. Where water supply is limited by a lack of investment in infrastructure or insufficient regulation or pricing, an area is considered to be affected by *economic* water scarcity, as is the case in much of Sub-Saharan Africa. Some 1.2 billion people live in areas affected by physical water scarcity, and 1.6 billion people live in areas affected by economic water scarcity[8].

The drivers that impact on water security are divided between pressures on supply and pressures on demand.

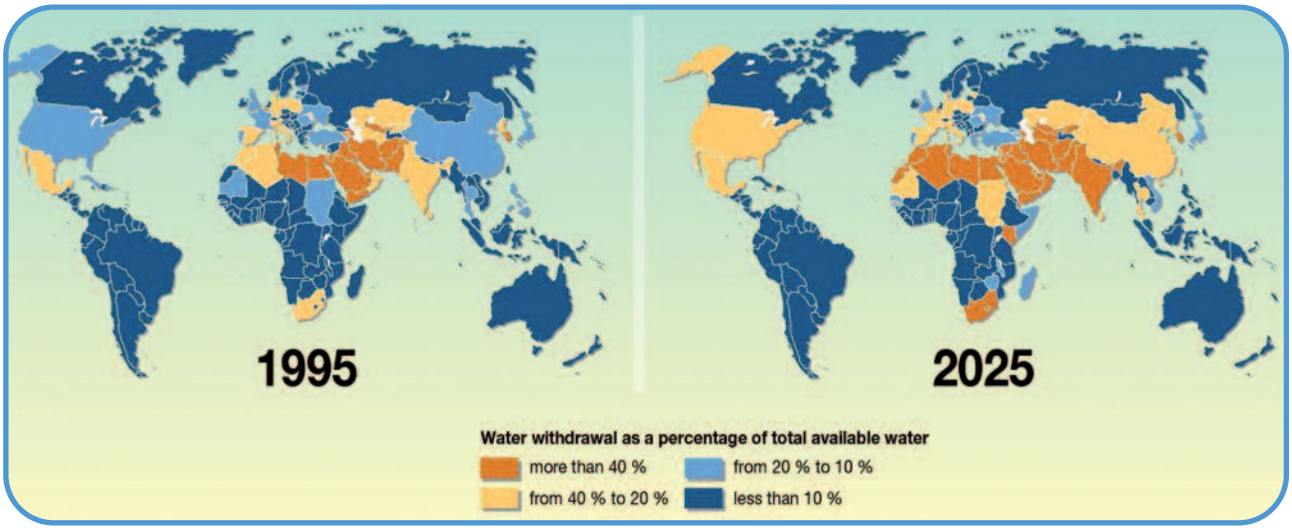


Figure 2 Global distribution of water stress for 1995 and predicted for 2025[9]

3. Pressures on water supply

3.1 Climate change

Water is at the heart of the changing climate in terms of shifting weather patterns more intense hurricanes, typhoons, storms, floods, droughts and the effects of glacial melt, snowmelt, evaporations and evapotranspiration and, of course, sea level rise.

Mean precipitation is expected to increase in the tropics and high latitudes, and decrease in the sub-tropics and mid latitudes[10]. Those areas experiencing reductions in precipitation are likely to be amongst the poorest[11]. It is also very likely that precipitation will become more variable in future[12], both spatially and temporally. For example, irregularities in the El Niño phenomenon have led to a reduction in precipitation in Australia, leading to a long running drought in the south-east. Studies indicate that, in future, changing patterns of precipitation will increase the risk of flooding and drought. Increased variability of precipitation will impact on the timely supply of water resources, and complicate water security efforts. There will be increased runoff in certain parts of the world (East Africa, India, China) and reductions in runoff in other regions (Mediterranean, North Africa)[13].

It is estimated that one sixth of the world's population live in catchments fed by snowmelt or glacier melt that provide reliable water storage and supply[14]. Gradually increasing temperatures will decrease the storage capacity of these glaciers, increasing water supply in the short term, but significantly reducing supply and altering river flow regimes in the long term. Examples are the large agricultural areas in the populous Northern Territory of India, in China[15] and, in the Andes, La Paz, Bolivia[16].

3.2 Multinational use of water basins and aquifers

Over 300 river basins span more than one country[17]. This means that changes to the catchment regime made in one country can lead to changes in water availability in another, creating the potential for conflict. Although conflict is historically rare (especially at the international level), research identifies 37 examples over the past 50 years[18]. One example is Turkey and Syria[19], where the development of Turkey's Southeast Anatolia Project, a very large irrigation system, has taken much of the available water on the Euphrates leading to conflict with downstream Syria.

3.3 Water supply infrastructure

Issues associated with ageing and poorly functioning water infrastructure is a challenge for agricultural and urban water supply[20]. In urban areas water supply and sanitation networks are often insufficient and subject to failure[21] (with associated high levels of leakage) a problem which is compounded by uncontrolled expansion of urban areas[22]. By 2030 60% of the world's population will live in urban areas and investment in public infrastructure is well below what is required in many countries including the developed ones. The ageing of costly irrigation infrastructure has been identified as a problem in many parts of the World, and has been the catalyst for water security planning[23]. In India, for example, there is an enormous backlog of deferred maintenance in irrigation infrastructure - the implicit philosophy

"Intermittency (flood or drought) may not be a disaster for everyone - the varying impacts and intensities of the hazard relate to existing patterns of vulnerability. Social, economic and political processes influence how flood or drought affects people."

Sue Cavill, Engineers Against Poverty

has been aptly described as 'Build-Neglect-Rebuild'[24]. Poorly functioning public irrigation infrastructure has led farmers to switch to self-developed groundwater supplies, which in many places are now over-abstracted[25] and can become non-renewable.

3.4 Intermittency

Developing countries are most at risk from drought (and flood) and inadequately managed or developed water infrastructure has a significant impact on their short term economic prospects. If such countries are unable to cope during periods of intermittency, they find themselves in an unending cycle of stagnation, making medium to long term planning an insurmountable problem.

Since 1970, the intensity and duration of droughts has increased, particularly in the tropics and subtropics, where higher temperatures have also been seen in conjunction with an increased frequency of heavy precipitation events.[26]

3.5 Water quality and environmental assets

Deterioration of surface or groundwater quality makes "raw"* water more difficult or impossible to treat. Increased flooding results in land degradation and an increase in contaminants washed into watercourses.[27]

Human actions are also a significant contributory factor in the deterioration of water quality. Eutrophication of water supplies is identified as a significant water quality issue globally[28]. Wastewater, industrial effluent and nutrient rich water from agriculture cause a rapid increase in algae and microscopic organisms in watercourses leading to oxygen depletion which damages the ecosystem: this cycle could be exacerbated by the predicted temperature changes associated with climate change and by the increased agricultural activity required to feed a growing a population, exacerbated by the widespread use of more fertilisers.

Pollution of groundwater supplies is also a significant contribution to water scarcity, with a number of major cities having to switch from groundwater supplies because of pollution[29]. Many active aquifers that are replenished by infiltration suffer from unsustainable over-abstraction, such as in Almeria in Spain[30]. Over-abstracted aquifers run the risk of saltwater intrusion and pollution, affecting their long term viability[31]. The Azraq basin is one of the most important groundwater basins in Jordan, supplying Amman with drinking water. However, as a result of over pumping from the shallow groundwater aquifers, the water level has dropped dramatically, resulting in salinisation of the source.

Environmental assets have a significant social and economic benefit as well as contributing to health and overall well being. Yet, in direct competition with agriculture, industry and domestic uses, environmental water requirements are often overlooked. An audit of global freshwater ecosystems has shown that the majority are declining or in a state of stress[32].

*Raw water is water taken from the environment, which is subsequently treated or purified to produce potable water in a water purification works. Raw water should not be considered safe for drinking or washing without further treatment

3.6 Degradation of fossil groundwater supplies

In many arid and semi-arid areas fossil groundwater supplies are the only reliable source of water. However, as there is typically very limited recharging, mining of these resources is almost always unsustainable. Mining of fossil groundwater[33] resources is most significant in North Africa and the Middle East: in Libya, Algeria and Saudi Arabia it is the main water source[34]. A well documented example[35], the Great Man-Made River Project in Libya, takes vast quantities of fossil water from deep wells in Nubian Sandstone Aquifer System in the Sahara desert and transports it 1,600 km to coastal towns and farms for irrigation. Although this scheme is expected to deliver water for many years and could be considered as reducing water scarcity, eventually the resource will be depleted and an alternative solution will be needed.

Countries in the Arabian Peninsula are now beginning to explore alternatives, based on the knowledge that fossil groundwater supplies are unsustainable[36].

4. Pressures on demand

4.1 Agriculture

Water for agriculture water currently accounts for 70% of all water use[37] and over 90% in some countries such as India[38]. It is estimated that a doubling of food production will be required over the next 40 years[39]. In 2008, there was a substantial increase in the global price of staple foods. This highlighted the interdependence of global systems, and brought about an increased focus on food security, leading the Royal Society to state that "it is now clear that global food insecurity is a chronic problem that is set to worsen"[40].

It could be argued that water for agriculture and, therefore predominantly, food does not currently benefit from a sufficiently strong voice on the global stage, where water supply and sanitation currently dominate. In order to elevate water for agriculture up the agenda on the global scene, water engineers, farmers, economists and policy makers will need to improve their communications with one another. Organisations such as *Agricultural water for Africa* (AgWA) have been established to share knowledge and mobilise resources so that the importance of water is recognised in a global context.

4.2 Changes in diet

Dietary habits are predicted to change in the next century beyond those caused by an increasingly ageing population. It is predicted that there will be an increase in per capita food consumption[41], with diets becoming more nutritious and diversified. In particular, there will be an increase in the consumption of vegetable oils and meats and a relative reduction in the consumption of wheat and rice[42]. Changes in the world's diet will also put an added pressure on water as more meat and vegetable oils are consumed in place of grains and pulses. One kilogram of beef requires 15,500 litres of water to produce, while the equivalent amount of wheat requires only 1,300 litres.[43]

4.3 Industry

It is estimated that energy and industry account for approximately 20% of global water use[44]; significantly more in the UK[45]. Water is fundamental to the processing, extraction and generation of almost all forms of energy.[46]

Given the global shift in manufacturing from older to more recently industrialised nations, the pattern of industrial abstraction and use is changing. Water abstracted by industry in the USA and UK has fallen in recent years, in part due to improvements in the efficiency of water use, but mainly through a transfer of manufacturing overseas. Abstraction of water by industrial use in China, India and other south East Asian countries continues to rise.

Industry is a major source of water pollution with some 300-500 million tonnes of heavy metals, solvents, toxic sludge and other wastes accumulating each year. This creates, or contributes to, water stress, especially in rapidly industrialising economies by reducing the quality of

'receiving' waters. Industries based on organic raw materials are the most significant contributors to the organic pollutant load with the food sector being the most significant polluter.[47]

Interest in biofuels has risen in recent years because of attempts to find low carbon alternatives to petroleum, with the EU setting minimum targets in 2003 for their use in road transport fuels by 2010. The high water consumption of biofuels has meant that attempts to alleviate the problem of energy security and climate change have exacerbated problems with food and water security[48]. Other low carbon energy sources such as wind and solar energy are far less water intensive and there are also opportunities to use the biological wastes from food production in the manufacture of second generation biofuels.

The amount of energy required to transport, treat and extract water is rarely recognised. Water is a very heavy resource (1 cubic metre has a mass of 1 tonne), and abstracting it from aquifers or transporting it requires significant quantities of energy. To illustrate the amount of energy required, it is estimated that as much as 19% of electricity and 33% of natural gas in California is used in water related activities[49]. If the energy required for water related activities is based on fossil fuels, it could have a significant impact on greenhouse gas emissions.

4.4 Population growth and distribution

The world population tripled in the 20th century and is set to increase by a further 40-50% in the next 50 years[50]. It is estimated that, by 2025, the global population will be 8 billion people[51]. The increase in demand for food to feed the extra population will see a subsequent increase in demand for water for agriculture.

However, an absolute increase in population is not the sole demographic driver of water scarcity. Changes in the location of population will also have a significant effect on water availability. On a global scale, there will be a small reduction in population in developed countries and significant increases in populations in developing countries, many of which are already suffering from water scarcity. It is estimated that increases in population could be up to 500% in some sub-Saharan African countries between 2000 and 2100[52]; more than 60% of the world's population growth in this period will occur in South Asia and Sub-Saharan Africa[53].

Increasing urbanisation will lead to 60% of the global population living in cities by 2030[54]. Cities draw in resources such as water from increasingly wide areas[55]. This often puts cities in competition with agriculture for water supplies[56]. The growth in megacities is set to continue, with population increases of 60-75% predicted between 2004 and 2015 in megacities of the developing world, such as Jakarta, Dhaka and Lagos[57]. This will put increasing pressure on water supply systems in these countries. In China, Beijing is already facing a water deficit that it is trying to manage through the South-North water transfer scheme and by increasing the use of reclaimed water for non-potable use.[58]

"The costs of water insecurity are huge. Floods in 2003 cost the Chinese economy £8.5 billion, whilst those in 2000 in Mozambique resulted in direct costs of $600 million and a reduction in GDP growth from 7.5% to 1.6% in one year."

Evidence submitted by DFID to RAE/ICE/CIWEM

5. Economic impact

Water security has a significant impact on a nation's or a continent's economic stability. For example, it is estimated that the ongoing drought in Australia reduced GDP by 1% in 2006-07.

The global financial crisis has been described by some as an opportunity for the water crisis[59]. While the financial crisis may be focusing the minds of those in the financial sector, the World Economic Forum makes the claim that water could be the proximate cause of the next global crisis[60]. Private investment in water clearly has the potential to improve water security where such investment can be commercially attractive, but the capacity of nations to invest in the future of water security will be determined, to some extent, by the recovery from the financial crisis. Correspondingly, the level of water security could have significant impact on the economic stability and, hence, the speed at which some countries can recover from the financial crisis in the first place.

5.1 Aid and development

Given the impending worsening of water security, particular in some developing countries, UK Government should put water right at the centre of its international development policy. There should be recognition that infrastructure development is of no use on its own unless the institutional capacity is developed in country and all levels of stakeholders are engaged to make it work.

The importance of water and sanitation within international development is clear. Sub-Saharan African countries are estimated to lose 5% of their GDP each year as a result of poor water and sanitation[61] and it is estimated that, for $1 of investment in water and sanitation in these countries, $8 of benefit could be accrued[62].

However, to ensure the sustainable use of water with regard to all development programmes rather than those explicitly directed at water and sanitation, US Aid, for example, links water security to much broader development and societal issues[63]. Building on existing initiatives, the Global Framework for Action on Sanitation and Water Supply (GF4A) is a political initiative initiated by the governments of the Netherlands and the UK. It provides a global platform to bring political focus and accountability to the sanitation and water supply sectors and help donors and development partners to coordinate their efforts and to direct resources where they are needed most. The new UN-Water Global Annual Assessment of Sanitation and Drinking - Water (GLAAS) report will be a resource for the GF4A and the first of these annual reports will be published early in 2010[64].

'We would argue that integrated water management is going to require a cultural change, policy changes and institutional reform. In order to deliver Integrated Urban Water Management (IUWM) and to utilise novel approaches we need to change regulations and standards so that they are more flexible and open to novel systems.'

– Technology Strategy Board & Knowledge Transfer Network

6. Tackling threats to water security

The scale and complexity of the challenge mean that responses to water in-security must seek to integrate supply orientated and demand orientated measures[65] through policy, governance and regulation, cultural change and institutional reform, as well as through better approaches to management and application of new technologies and techniques.

6.1 Governance and regulation

Water security is not only about a sufficiency of water but also about recognising the true value of water and managing it accordingly[66]. There is a need for better governance and management at all scales[67]; global, regional, national, local, as well as at the catchment level and a need for synergy between them. In situations where rivers cross national boundaries or lakes are shared between countries, trans-boundary agreements for water allocation and sharing need to be enshrined within international treaties. Tackling threats to global water security requires responses tailored to the individual country's political, social, economic, environmental, financial and cultural conditions but with a framework of international coordination.

Case Study: UK regulation

The privatised water industry in England and Wales is subject to extensive economic, environmental and water quality regulation. Government is responsible for developing public policy on water and enacting associated legislation. Ofwat is responsible for the economic regulation of privately run water supply and sewerage companies. The Environment Agency is responsible for licensing of abstraction from the environment and the award of consents for discharges of treated wastewater into the environment. The Drinking Water Inspectorate is responsible for checking that water companies supply water that is safe to drink and meets the standards set out in legislation.

Water companies develop their own water resources and investment plans, based on a 25 year planning period. However, Ofwat reviews water company plans and is responsible for setting price limits, every five years, following price reviews which consider operational expenditure, capital charges as a result of the capital investment programme and return on investors' capital. The short term nature of these cycles does not aid water companies' planning.[68]

There is increasing attention on sharing of the water resource among and between users, including the environment. In the UK, the Environment Agency has the power to grant new water abstraction and discharge licences and amend existing licences. Catchment Abstraction Management Strategies (CAMS) are used by the Environment Agency to manage and administer the system of water resources of a catchment. They provide a baseline of water availability and a classification system to indicate the relative balance between the environmental requirements and how much is licensed for abstraction already; whether further abstractions are possible; and areas where abstraction may need to be reduced[69].

Over the next few years, water resources in the EU will be significantly affected by the Water Framework Directive (WFD)[70]. The WFD is the most substantial piece of EU water legislation to date and according to this Directive, Member States must aim to reach good chemical and ecological status in inland and coastal waters by 2015. It is designed to improve and integrate the way water bodies are managed throughout Europe and will have significant impacts on abstraction and discharge consents.

While the Water Framework Directive's primary objective is on the ecological 'health' of the water environment, it impacts on the wider water system as supporting the ecological status requires sufficient water flows. All abstraction licences granted are now 'time-limited', which means that after an agreed period these licences may be renewed in full, reduced or revoked. Those catchments identified as over-licensed or over-abstracted within the CAMS framework, will likely have licence volumes reduced or not restored in coming years. This has implications for water supply in England and Wales, particularly in the water stressed areas of South East England.

Discharge consents for treated wastewater will also tighten under the WFD. In London, for example, of all 47 river water bodies, only one currently achieves good ecological status, with 16 having poor ecological status. The upper and middle sections of the Thames Estuary both currently achieve moderate ecological status. London's 16 lakes generally have a higher standard of water quality, with 10 achieving good ecological status[71].

Case Study: South African Water reform[72]

The political change inherent in moving to post-apartheid democracy created an ideal opportunity to deal with one of the constraints to South Africa's economic and social development – water reform. Despite extensive infrastructure, including sufficient dam storage to accumulate 65% of annual flows, by 1990 water use was approaching the limits of what could be made economically and nationally available on a reliable basis. A range of consultative processes drew a wide community into a five year debate to produce a national water policy finalised by Department of Water Affairs (DWAF) which guided the drafting of new water resource legislation. The mandate of DWAF was expanded to include water supply and sanitation services, preserving continuity of technical competencies and institutional memory.

The big ideas included clarification of the legal status of water as an 'invisible national resource", with national government responsible for its custodianship as a public trust. A vision was adopted for "the objective of managing the quantity, quality and reliability of the nation's water resources to achieve optimum long term social and economic benefit for society from their use" South Africa was going to have to manage the resource and the tension between growing demand and finite supply and ensure that the limited water available was to be used not just productively and beneficially, but optimally.

The requirement that water be reserved to meet environmental needs put the environment centre stage. Another critical element of the new policy was to establish that water rights were user rights (rather than property rights), and as such become subject to regulation. This recognised that water use will change with time and water use rights have a limited life span dependent on the type of use. The trading of rights was a contentious issue – concerns that inland farmers would sell their rights to industry and leave populations stranded – so as a result, trades have to be registered, with stricter regulatory control over transfers between different sectors and sub-catchments. The notion that conservation and demand management were projects with as much validity as dam construction and inter-basin transfers was also introduced. Priority was also given to an intense national programme to provide safe water to the 12 million South Africans who did not have it. Innovations such as free basic water were part of a broader pricing policy for water services.

The 1998 National Water Act required the preparation of a National Water Resources Strategy, the first of which was published in 2004. This made South Africa one of the first countries to meet the target for the development of national Integrated Water Resource Management (IWRM) and water efficiency strategies set up at the 2002 World Summit on Sustainable Development. Equity and efficiency were addressed by establishing water use as a temporary right, allowing transfers from one use to another, and for economic users, promoting the "user pays" and the "polluter pays" principles.

Now, 14 million people have access to safe drinking water, even in areas where the resource is overexploited, and the priority of basic human needs over all other activities is respected. Good management, secure allocations and an explicit pricing policy have made it possible to fund a number of large projects from private-sector resources.

As a result of these changes in water management, the following have been achieved:-

- Water productivity (contributions to GDP or jobs per m^3), and the real price of water for economic use, have increased
- agricultural employment has increased significantly owing to the expansion of irrigation along the Orange River and Northern Cape,
- no significant water shortages have affected the key economic activities over the past decade despite some severe droughts.
- competing demands for water are being managed successfully – a number of mining projects in water scarce areas are taking their water supplies from municipal wastewater discharges.

Pressure to reduce pollution has seen a number of major industries based in sensitive inland catchments move towards zero discharge processes; domestic water consumption grew by only 20% between 2001 and 2006, while the number of people served increased by 50%. Overall there is a sense that water management is not just staying ahead of economic and social development, but is actively contributing to it.

6.2 The cost of water

Water has traditionally been regarded as a free resource. Any costs for water are usually associated with the cost of processing and delivering alone, rather than assigning any value to the resource[73]. Free or highly undervalued water gives limited incentive for water efficiency. There is growing interest internationally in the use of water pricing to reduce demand as well as to generate revenue to cover the cost of providing water supplies and maintaining infrastructure.

6.2.1 Pricing

The effectiveness of pricing in influencing demand varies between water users[74] For municipal water demand, pricing can be effective when

'Too many water projects, particularly in the Developing World, have suffered from exchange rate fluctuations. The projects may have been very successful, but had to be cancelled due to this debt issue. Mechanisms that encourage local people or expatriates to invest in debt products must be found as this removes the foreign exchange risk.'

– David Lloyd-Owen

combined with raising user awareness. In the case of water for irrigation, pricing is more complex because the amount of water consumed is difficult to measure and farmer behaviour may not be sensitive to price until the price of water is several times that of the cost of providing water[75]. Large increases in the price of surface water may cause farmers to use groundwater instead which is relatively unregulated by comparison.

Although tradable water rights schemes are in place in Australia, Chile, South Africa and the western USA, the design of a trading system is fundamental to ensuring its success, and establishing the necessary institutional framework can take considerable time. The World Development Report[76] concludes that water trading may be viable over the longer term, but does not present a short term option for most developing countries.

6.3 Funding mechanisms

The World Bank notes that many countries face a major challenge in developing and maintaining appropriate water systems infrastructure. Financial institutions are likely to play a key role in making up this shortfall. Firstly, however, better information on likely costs and barriers to their implementation is needed. This may help to close the water supply-demand gap and help meet the Millennium Development Goals in the long run.

Discussion on the financing of water projects has typically only been made in relation to water and wastewater supply, though recently broader viewpoints have been adopted[77]. For example, financing may be required at a user level to invest in more water efficient methods, such as, for example, the provision of credit to farmers to improve irrigation efficiency by investing in drip irrigation.

Public finance still accounts for 70% of investment in the domestic water supply sector globally, despite the recent rise in the number of people supplied by the private sector[78]. Public sector financing means that assets are owned by the public sector, and government controls the price and supply of water. Public spending faces competing demands, particularly so in periods of poor economic growth, and many countries have ageing assets and many countries with less developed but growing economies under-spend on water resources infrastructure.

Private sector involvement spans a range of activities sharing the responsibility for water between the public and private sector. In some countries, (France, England, Wales and the Czech Republic), water services are operated by regulated private companies for a defined geographical area. The UK's water sector is made up of 12 water and sewerage service providers and 14 water suppliers. In England and Wales, the companies are privately owned. Welsh Water, which supplies services in Wales, is a not-for-profit company. Scotland and Northern Ireland each have single water and sewage service providers (Scottish Water and Northern Ireland Water) that are in public ownership but rely upon private companies for delivery of many of their services. The water industry in England and Wales is financed by customer revenues and by outside investment.

Private sector involvement is not a global panacea for tackling water security, and many agencies, including the UN take a cautious approach to its adoption in developing countries. Of particular concern, are unsuitable regulatory structures, issues of corruption and the need for public funding of infrastructure[79].

Recent work by the World Economic Forum has looked at '"Innovative Water Partnerships", or public-private-community partnerships (PPCP)[80]. These partnerships, supported by USAID and SDC, are multi-stakeholder approaches to leveraging finance into the broader water sector. Examples from India and South Africa include the financing schemes for watershed management and reuse of wastewater. This study concluded that, while private sector involvement has significant potential for meeting funding gaps and increasing the efficiency, it should be tailored to the specific situation, and may not be appropriate everywhere.

"Recognising irrigation properly means coming at it simultaneously from a systems, water, technological, societal and policy point of view."

Bruce Lankford
School of International Development, UEA

7. New and better technologies, techniques and practices

Many of the technologies needed to address water security already exist but need to be refined, developed and improved, bringing challenges for research and development. When looking at the role that technology has in providing new sources of water, we must be conscious of the affect that it may have on the ecosystem.

7.1 Managing variability

Water storage in rivers, lakes, reservoirs and aquifers provides a means of managing variability in water availability, allowing stored water to be used during dry periods. In addition, the storage in some lakes and reservoirs can be managed to provide potential for the storage of excess flows during floods.

7.2 Surface water storage

There are over 48,000 large dams in operation worldwide. Surface water storage by means of dams can bring many benefits, such as energy, drinking water supply and water for irrigation. However, these benefits may come at great social and environmental cost caused by the displacement of people or impacts on the ecosystem caused by changes in flow and continuity of rivers. For a time, dam building slowed, as decision-makers learned of their harmful impacts, but in recent years, the number of new dam proposals has grown.

The World Commission on Dams (WCD)[81] was established to assess the past performance and future role of large dams. It concluded that, while dams have indeed made important contributions to human development, in too many cases an unacceptable and unnecessary price has been paid in terms of impact on communities and the environment. Key recommendations of the WCD include five "core values":

- equity
- sustainability
- efficiency
- participatory decision-making and accountability.

These values are underpinned by seven "strategic priorities":

- The need to gain public acceptance
- comprehensive assessment of all options
- addressing the impact of existing dams
- sustaining rivers and livelihoods
- recognising entitlements and sharing benefits
- ensuring compliance
- sharing rivers for peace and
- development and security.

The World Wide Fund for Nature points out that, five years after the WCD report, many dams are constructed without all of these issues being taken into account. However, the WWF[82] is not against dam construction per se, but states that "the development of new dams in accordance with the seven strategic priorities recommended by the WCD is the best way to ensure that dams really deliver their intended benefits and avoid unacceptable impacts".

7.3 Sustainable use of groundwater

Groundwater (except fossil groundwater) is naturally replenished, or recharged, through rainfall and surface water. It provides a cushion for coping with unreliable public supplies and rainfall, but it is far from well managed and in arid regions around the world, aquifers are overexploited[83].

Groundwater supplies are an important supply of water for agricultural and domestic use; 1.2 billion urban dwellers rely on groundwater for their water supply[84]. Groundwater acts as a long-term "reservoir" for the water cycle and can have residence times ranging from just days to 1,000s of years. Throughout the world, significant numbers of aquifers are being drawn upon at a rate that exceeds the natural recharge. Our understanding of aquifer yields is limited by their complex interactions with surface water and connections between numerous aquifers. This is clearly an area for more research into sustainable practices relating to groundwater withdrawals, the integrated management of groundwater and surface water systems, and actions to enhance natural and artificial aquifer recharge.

Aquifer Storage and Recovery (ASR) is the process of storing excess water underground when it is available, and recovering that water for use when supplies are short. This is widely used in the USA and Australia. In the UK, Thames Water is using ASR as part of its supply technology strategy for London.

7.4 Water efficiency in agriculture

Managing water use to meet future needs involves making water use more efficient. As agriculture accounts for around 70% of freshwater abstractions from surface and groundwater sources, increased efficiency can lead to large savings. The World Bank[85] notes the need to increase the productivity of water in rain-fed agriculture, which provides a livelihood for the majority of the world's poor, generates more than half the gross value of the world's crops and accounts for 80% of the world's crop water use. Measures such as mulching and conservation tillage help retain soil moisture, especially if supported by soil conservation measures to manage land cover. Small-scale rainwater harvesting helps provide an additional source of water for crops.

Irrigated agriculture is expected to produce a greater share of the world's food in the future as it may be more resilient (in the medium term) to climate change in all but the most water-scarce basins[86]. There is little scope for increasing the total area under irrigation, which is projected to increase by only 9% between 2000 and 2050[87]. This means that there will need to be an increase in the productivity of crops per unit area and per unit of water applied.

New technologies have the potential to increase water productivity (getting more "crop per drop") but these need to be combined with strong policies, well focused investments, and good institutional arrangements that allow farmers to participate in decision making and provide them with

Case Study: Improvements in irrigation in China

In the 1990s, China introduced water-saving measures and began to modernise its agricultural irrigation systems. China has some 400 large irrigation systems - each with an irrigated area of more than 20,000 hectares - which account for about a quarter of the country's total irrigated area of 56 million hectares. Modernisation included the application of new materials and technologies to upgrade irrigation system structures and the application of modern irrigation concepts and institutions to improve irrigation management. Water conveyance and irrigation intervals have been shortened, and water losses have been reduced. Agricultural output in the programme area increased by 46%, even though irrigation abstractions have fallen from about 80% of total water withdrawals in 1980 to 60% today, a dramatic reduction by improving water use efficiency.[90]

information and advice on how to get the most out of new infrastructure and technical developments[88].

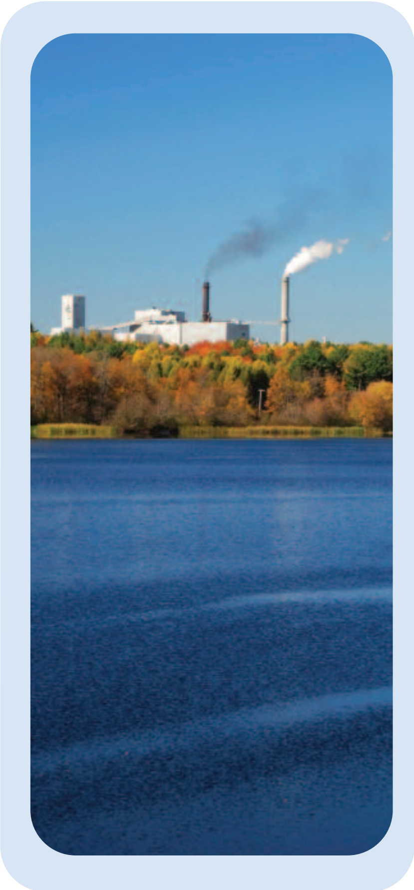
Improved surface irrigation methods such as level furrows, sprinkler and micro irrigation methods, and the use of advanced techniques of irrigation scheduling and timing can help improve water management at farm level. By monitoring water intake and growth, farmers can achieve greater precision in water application, and irrigating only when necessary. Remote sensing schemes are beginning to allow farmers to detect their crops' water taking into account meteorological data as well as soil moisture and biomass information[89]. More efficient water use is being combined with more widespread adoption of drought and heat tolerant crop varieties.

7.5 Water efficiency in industry

As the GDP of a nation grows, the abstraction of water for industrial purposes increases, from about 10% for low and middle income countries to around 60% for high GDP countries. Industrial water abstraction globally is estimated to rise to about 24% of total freshwater withdrawal in 2025[91]. Water availability is becoming critical in the power industry[92] for electricity generation. Water used for cooling by thermal and nuclear power plants is set to rise throughout the world as new power plants are commissioned. In some cases, it is not simply the availability of cooling water that is the issue, but that outflows from power stations can become warm enough to cause environmental damage on discharge.

Agenda 21, the United Nations' Programme of Action from the Earth Summit in Rio de Janeiro in 1992, urged industry to implement "more efficient production processes...hence minimizing or avoiding wastes" thereby enabling it to play a major role in reducing impacts on resource use and the environment. This was echoed in the World Summit on Sustainable Development, Plan of Implementation in 2002.

A proportion of the water abstracted by industry is consumptive, evaporated through use for cooling or embedded within industrial products, so that it is not available for use elsewhere in the basin. This proportion can be reduced by applying more efficient forms of cooling and the condensing and re-use of cooling water. The remainder is non-consumptive and is returned to surface/groundwater systems following its use in the production process, typically for washing/cooling and then returned as warm water or for sanitation needs within the manufacturing facility. Water treatment and re-use on site can significantly reduce water abstraction.



7.6 Water supply and distribution

Half the world's population live in cities and this is projected to rise to 70% by 2050. Of this, 95% of urban population growth will be in the developing world with small cities growing most rapidly.[93] Urban growth rates need to be matched by extension of public health infrastructure (including piped treated water, waste water systems) to ensure that communities are sustainable and benefit from the economies of scale that derive from lower per capita costs than in rural areas. Well planned urban development and related infrastructure are required to provide resilience to water related risks including water shortages and the threat of fluvial and coastal flooding.

A recent report by the UK's Council for Science and Technology (CST) examined the core sectors of national infrastructure, including water, and made recommendations to Government.[94] The report found that resilience against climate change is the most significant and complex longer-term challenge, noting potential impacts on pipe systems, wastewater treatment works, sewerage and dams. Current Government policy in the UK is committed to an integrated approach to the improvement of national infrastructure, including water infrastructure. Assessments of the country's long term infrastructure needs over a five to 50 year horizon have been informed by recent reports on critical infrastructure from the engineering profession.[95]

The national water resources strategy for England and Wales, recently published by the Environment Agency, notes that water companies have made progress in reducing and controlling leakage over the last decade, but notes that more needs to be done. An analysis of the application of best practice in finding and repairing leaks, managing pressure and replacing mains, if applied by all water companies, suggests that leakage could be reduced by 30 per cent from the level in 2009 (1,000 million litres per day) by 2025.[96]

7.7 Developing new sources

Another option in response to water shortage is the development of new sources of water. This option is appealing in that it has the potential to develop an increased supply of water or efficiency in its use, without necessarily having to compromise on our demand for water and lifestyle choices. However, when looking at the role of technology in providing new sources of water, we must be conscious of the effects that it can have on the ecosystem as a whole.

7.7.1 Desalination

Almost half of the world's desalting capacity is used in the Middle East and North Africa for municipal supplies. Saudi Arabia ranks first in total capacity installed (approximately 24% of the world's capacity) with the United States second (16%).[97] The largest desalination plant in Europe has been constructed by Thames Water to provide security of supply to London. A number of desalination plants have been built in Australia, but to date, most of the capacity is located in Western Australia. However, this trend will change over the coming five years as the large seawater plants on the Eastern States are commissioned and the total desalination capacity in Australia increases dramatically.[98]

The advantages of desalination are that it taps into a large resource of water (the oceans), increases supply rather than constraining demand, and can be widely implemented. Desalination plants have been proposed not just in developed countries, but also in developing countries. The main disadvantage of desalination is the cost and concerns over energy security, putting it at the mercy of fluctuating energy prices. Increased energy consumption will also lead to an increase in greenhouse gas emissions if the plant relies on non-renewable energy sources. There is also an issue with what to do with the highly concentrated brine by-product.

Desalination plants that operate using low-carbon energy have been proposed, with the first large scale plant of this kind constructed in Perth, Australia[99]. The extent to which sustainably powered desalination schemes could be technically feasible for providing significant amounts of water remains to be seen. The use of sustainable energy sources such as hydropower or biofuels may limit their viability as a solution, through negative impacts on the water-energy-food nexus.

7.7.2 Water recycling, reuse and harvesting

Recycling water is the process of removing solids and certain impurities from wastewater and using it again rather than discharging into surface water or the ocean. The reuse and recycling of water in industrial and domestic settings has the potential significantly to reduce the consumption of water in these environments. Harvested rainwater and recycled water can be used for activities such as toilet flushing, reducing overall domestic water consumption.

Currently, recycled water is used for purposes such as irrigation, dust control, and fighting fires. There is controversy about possible health and environmental effects for even these uses, let alone for re-use as potable water. In some locations however, such as Singapore and Namibia, waste water is given superior treatment and is used indirectly to supplement water sources that will eventually be used to supply potable water. Even in the UK, Thames Water has been investigating the potential to reuse water to supplement domestic supplies (indirect potable supply).

Industrial recycling of water has the potential for more significant savings of water. It also puts less pressure on natural water resources and can augment environmental flows. Given the relatively small proportion of water that is used domestically, the benefits of carrying out water recycling will be relatively small, though not insignificant, and is increasingly used in the water-scarce Middle East. Harvesting rainwater via water butts has benefits not just in replacing mains water supplies in houses, but also in reducing quick runoff and thus the risk of flooding.

8. Tools to support policy development

New and better tools are needed to support effective policy development and decision making and enable the effective and sustainable management of water resources.[100] These include:

- Increasing our knowledge about the world's water as a system. To manage water well, it is critical to know how much water is available and how much is being used for what purpose.[101]
- Developing a rigorous analytical framework to facilitate decision-making and investment into the water sector. This is a prerequisite for the efficient allocation of water as well as for limiting water consumption to sustainable levels in the face of significant areas of future uncertainty.
- Developing risk-based decision-making techniques to enable adaptation to climate change impacts as well as responding to the changing needs for food and energy security of a growing world population.
- Developing water system modelling techniques and the monitoring systems and data collection to validate them.

The nature and scope of these tools is broad. They deal with a spectrum of issues from the optimisation of water resource allocation and the simulation of the reliability of the balance between supply and demand (under various future planning scenarios) to the analysis of water needs and water use. The use of risk analysis and risk-based decision- making techniques is becoming more common, especially to address issues relating to the security and reliability of water supply, and the implications of uncertainty in developing sustainable water management plans.

In the business sector, there is a growing interest in understanding better the extent to which an individual, organisation or administrative unit is dependent on water and to what water related risks business is exposed and vulnerable. Water-related risks can be:

- physical, arising from threats to the reliable availability of sufficient water of an acceptable quality
- regulatory, associated with the regulation of water abstraction, use and the quality of water discharged; and
- risks to the reputation of organisations arising from the increasing competition for clean water among economic, social and environmental interests.[102]

A range of assessment tools seek to address these issues (e.g. Corporate Water Gauge, Water Footprinting)[103] and to help identify ways to reduce water use, and guiding policy (such as Coca Cola's Water Efficiency Toolkit[104].). The concept of "virtual" water has become a key concept in the understanding and communication of water issues and how they are linked to international trade, agriculture, climate change, economics and politics and is the basis of water footprint assessments being carried out by businesses (such as

SABMiller[105]) both in their own direct use and through their value chain. The concept of water footprinting can be applied at different levels. The Water Footprint Network has recently produced a Water Footprint Manual, which sets out methods for calculating footprints at different levels[106]. In 2008, the WWF assessed the size of the UK's water footprint, calculating that each person in the UK used 4,645 litres per day[107] of mostly virtual water.

The water marginal cost curve developed by McKinsey is another potentially powerful tool for policy and decision makers.[108] The tool estimates, for a range of options, the incremental availability of water and the cost of each option, and its application in several parts of the world has indicated that more efficient water use in agriculture is a fundamental part of the global water security solution. Similar insight is provided by the analytic techniques applied in the UK by the Environment Agency and water companies under the Economics of Balancing Supply and Demand water resources planning process[109].

8.1 Trans-boundary agreements and conflicts

Trans-boundary disputes are likely to be an increasing source of risk in the future, with conflicts over water, though historically rare, expected by some to increase.[110]

In situations where rivers cross national boundaries or lakes are shared between countries, trans-boundary agreements for water allocation and sharing may be enshrined within international treaties. The Indus Treaty was agreed between India and Pakistan in 1960, following over a decade of negotiations, assigning the use of water from different tributaries to each country. The treaty was agreed in spite of ongoing political tensions between both countries. The security of supply guaranteed by the treaty allowed significant development of irrigated land (particularly by Pakistan), and of hydropower (particularly by India). Pakistan has developed its irrigated area from eight million to 18 million hectares in 2001; something that has been directly attributed to the success of the Treaty.[111] Agreements such as the Indus Treaty show that trans-boundary issues can be resolved in spite of political tensions between users. Similar agreements may be required in areas where water security issues exist against a backdrop of political tensions, such as, for example the Euphrates-Tigris catchment and basin.

8.2 Engaging the public

The implementation by governments and public authorities of policy and strategic (large scale technological) responses to water scarcity problems rely for their success on a positive response from individuals and community stakeholder groups. This requires awareness and understanding by all parties of the key issues and the views and likely reaction of local communities and individuals and, in turn, ensuring that such issues are included and addressed in public debate on the project as well as the broader debate on the sustainable use of resources.

Engineers and policy makers have a role to play in engaging the public on water security and its implications for such issues as the more careful use of water, changes in dietary and lifestyle habits, an awareness of the international implications of virtual water and the relationship between water, the food we eat and the energy we consume.

Where there is water scarcity, people adapt to the amount of water that they have to consume. During the prolonged droughts of recent years in Australia there has been a measurable reduction in water consumption. In the UK, during the droughts of 2006-07, a decline in urban consumption was linked to an advertising campaign by water companies.[112] In many developing countries, there are limited alternatives to adapting consumption to water availability.

The UK Government Department of the Environment, Food and Rural Affairs' Water Use Aspirations[113] for 2030 are centred on assumptions that consumers will use water wisely, appreciating its value and understanding the consequences of wasting it. DEFRA is aiming for reduced per capita consumption of water from current levels of around 145 litres per person per day, to an average of 130 litres per person per day by 2030, or 120 litres per person per day if new technological developments and innovation bear fruit. Achieving a reduction of this scale represents a significant challenge in raising awareness and changing customer attitudes, especially current perceptions of the value of water, attitudes to the availability of water and the price people are prepared to pay for what they perceive to be a right rather than a commodity. Informing and engaging the public about water use and pricing could catalyse changes in behaviour that are potentially significant in reducing water stress, and in successfully implementing fundamental changes to water provision such as water pricing and trading.

Reducing individual water consumption means wasting less food, recycling products[114], as well as reducing mains water use in the domestic environment[115]. Demand side management techniques, such as rainwater harvesting, grey-water recycling and volumetric charging, have the potential to reduce consumption in the domestic environment. The choice to adopt technologies and practices such as these lies only to a limited extent with the individual; however people could be encouraged or incentivised to adopt such technologies and practices as they become available.

Case Study: Lufumbu Village Water Project, Tanzania[118]

In 1992, the Government of Tanzania conducted a survey to determine the villages in greatest need of water so that Government-funded water projects could be prioritised. For reasons of budgetary constraint, Lufumbu was not selected. This disappointed the villagers, who sat down together and voted to raise their own resources to establish a village water supply scheme.

The scheme, which relies on a simple gravity principle, was designed jointly by the villagers and water technicians. Its costs, which were under US$50,000, were shared between the villagers (48 per cent), the Roman Catholic Church (10 per cent) and the United Nations Development Programme (42 per cent). With 10 kilometres of mains, a reservoir tank of 60,000 litres and 56 drawing points, the scheme was designed to serve the whole community.

Upon completion, the Lufumbu water scheme produced a wide range of benefits going far beyond the anticipated objective. Access to water was dramatically improved, leading to a significant reduction in the incidence of water borne disease in the community. Agricultural productivity increased, while additional initiatives to establish nurseries for coffee have contributed to the expansion of coffee farming. House-building also benefited from this better access to water, as water is required to make house bricks. Now, over 300 modern brick houses can be found around the village.

Lufumbu village shows how even infrastructure projects, which are assumed to be more technical and complex than other projects, can be owned by a community of poor villagers. And the water governance in this project has proved particularly efficient and transparent. The management of the scheme is ensured by a democratically elected water committee made up of villagers who are given training.

Consumers and citizens have the power to enact change in consumption through their purchasing decisions. Reputational risk is identified by businesses as one of the significant risks of adopting unsustainable water practice.[116] The notion is that consumers actively engage in green issues and will choose alternative products if they believe a company are conducting its business unsustainably. The Coca-Cola bottling plant in India is one example of consumers reacting to perceived poor practice by the company.[117] Since this incident, Coca-Cola and other beverage companies have been much more concerned about their activities regarding water use. As the public becomes more aware of water security issues, reducing the water footprint of products and services, and their supply chains, will become a core component of any businesses' corporate social responsibility strategy.

9. Conclusions and recommendations

Water underpins the very fabric of human life – our food and drink, the clothes we wear, the landscapes we enjoy, the societies we live in, the length and quality of our lives. The essential role that water plays in national life – in energy supply, infrastructure, economic growth, health-care, education and culture – makes water a central concern for national policies. Because the water cycle is global, the availability, use and security of water transcend local, national and even continental boundaries.

Water security is under severe pressure from many sources; a world population explosion, rapid shifts of people from rural to urban areas, the impact of dietary change as countries develop, increasing pollution of water resources, the over-abstraction of groundwater and the not insignificant issues created by climate change.

The world is far from water secure. In many parts of the world the demand for water is already much greater than the available supply. This is not an issue that affects only developing countries, where water infrastructure is poor and where many people do not have access to safe drinking water, but also of the developed world, where burgeoning demand simply cannot continue to be met. Water for agriculture and, therefore, food is not given a sufficient attention on the global stage, where water supply and sanitation issues currently dominate. In order to move water for agriculture up the agenda on the global scene, water engineers, farmers, economists and policy makers will need to improve their communications with one another.

Water has traditionally been regarded as a free resource. Any costs for water are usually associated with the cost of processing and delivery alone, rather than assigning any inherent value to the resource. Free, or greatly undervalued, water gives little incentive for water efficiency. There is growing interest internationally in the use of water pricing to reduce demand as well as to generate revenue to cover the cost of providing water supplies and maintaining infrastructure.

9.1 Findings

Water management solutions should be considered in the context of the entire water system, from "cloud to coast" as well as the implications immediately upstream and downstream. In this systems approach, all types of water must be considered together and in this context, the flows and uses of water in a catchment area feeding the soil (green water), free water in rivers and reservoirs (blue water) and used or waste water (grey water) all need to be included. Such an approach can lead to significant efficiencies in managing water systems.

The impact of policy in one nation can have impact on the water security of other nations. There is a need for governance at all scales – global, regional, national, local, as well as at the catchment level and a need for linkages between these scales. In situations where rivers cross national boundaries or lakes are shared between countries, trans-boundary agreements for water allocation and sharing may be enshrined within international treaties. Tackling threats to global water security requires responses tailored to the individual country's political, social, economic, environmental, financial and cultural conditions, and will, in most cases, require international coordination.

Developed nations are in a position to meet some of their water need by importing "virtual" water in the form of goods and services from other countries. The UK is reliant on food, energy and goods that require water in their production and transportation by and from countries that are themselves under water stress. This hidden water accounts for over 2/3 of the UK's water footprint. The UK therefore has a responsibility, not only to manage its own water resources sustainably, but to provide leadership to enable the development and implementation of global solutions. Water security should become a core component of UK policy making. Government must assess the interrelationship between water, food and energy security in UK with a view to achieving an optimal balance of aligned national policy.

The importance of water security to national security should be a core component of policy making. Water security should be considered as part of climate change mitigation and adaptation policy and the global impacts on water security of our national and international policies need to be assessed. The technologies, practices and management approaches that will be required to address water security issues must be identified and supported through research and development. Government should review the needs for public engagement, education and awareness-raising around the subject water security.

Given the impending worsening of water security, particular in some developing countries, UK Government should put water at the centre of its international development policy. There should be recognition that infrastructure development is of no use on its own unless the institutional capacity is developed in country and all levels of stakeholders are engaged to make it work.

Improvements in climate modelling are crucial to help predict the temporal and spatial distribution of the effects of water scarcity. As well as fulfilling their traditional role in designing and building water infrastructure and management systems, engineers and policy makers must engage with communities, with society and with industry about demand management, sustainability strategies and their impact on daily life.

The UK professional engineering bodies have a role to play in helping embed awareness of the water security challenges among their global membership. The professional qualifications that the engineering institutions administer can ensure holders know and understand the appropriate technologies, legislative frameworks and latest best practice for taking a systems based approach to water security. Such organisations also have a role to play in coordinating dialogue with the public.

The education and training of engineers needs to combine experience-led technical learning and systems thinking with modules on such issues as sustainability, ethical and societal dimensions of engineering and the impact of trade and transboundary conflicts.

Businesses can examine its supply chains and production processes to assess and reduce their water footprint as a core component of their corporate and social responsibility strategies. Their analysis should not be restricted to their home country but also to those regions from where they import goods, materials and services. A commitment to openness and transparency about the impact of business operation on water supplies in country will help create a "stress map" that will support international policymaking. Business should be encouraged and incentivised to develop tools to support effective policy development and decision making to enable sustainable management of water resources.

The regulation of the water sector globally needs to be focused on integrated water resource management and sustainability. All too often there is little synergy between long term water resource management and the need to provide water and sanitation services. Indeed Governments often view the water sector as purely the utility operators and neglect the water resource, ecosystem and amenity functions. This is a common issue across the developed and developing world. For example in the UK the water utilities have been required in the recently completed price review process, to produce a 25 year forward view by the regulator Ofwat. Whilst this is welcome, the regulator has focused in reality, only on the companies' investment plans over the next five year period.

This disconnect is a problem and highlights the need to develop sustainable regulation for the water sector. In Europe, the EU Water Framework Directive, which concentrates of the health of aquatic ecosystems and their ecological quality, is being brought into force in all member states. The implementation of this directive will challenge existing regulatory systems to accommodate a more sustainable approach.

This example highlights the importance of developing sustainable water regulation in the context of full integrated water resource management (IWRM).

9.2 New knowledge and engagement

Changes in water consumption at an individual level will be crucial to tackling water scarcity. Achieving a significant reduction in demand represents a significant challenge in raising awareness and changing customer attitudes. The choice to adopt technologies and practices to reduce consumption lies, to a certain extent, with the individual who needs to be encouraged or incentivised to change behaviours.

Many of the technologies, techniques and practices needed to address water security already exist but need to be refined, developed or improved. When considering the role of technology in providing new sources of water, it is important to be conscious of the effects that it can have on the ecosystem as a whole. UK research must rise to the challenges of developing and improving the new tools and technologies which will contribute to solving of water scarcity and delivering global water security. Examples include: water resource allocation and optimisation models, predictive climate change water scarcity impact models, development of new water policy, regulation and governance frameworks and development of innovative financing mechanisms for water infrastructure.

New knowledge and sustainable technologies or practices that need to be developed include:

- management of existing sources to provide potential for the storage of excess flows during floods
- surface water storage by dams in line with the World Commission on Dams' (WCD)[119] five 'core values'
- sustainable use of groundwater and better understanding of aquifers
- water efficiency in agriculture through water management and drainage and improved surface irrigation alongside drought-heat tolerant crop varieties (in parallel with improvements in plant breeding or genetic manipulation to reduce irrigation demand)
- more water efficient industrial production processes
- better management of water supply and distribution systems
- development of new sources and improving performance of existing sources
- desalination of seawater or brackish water including strategies for handling concentrated brine waste streams
- better modelling of water systems with improved monitoring, data collection and validation.

9.3 Recommendations

1. Inter-governmental bodies such as the WTO, and key discussion fora such as the UNFCCC must elevate the issues of water security in their strategies. Water footprints and virtual water content of globally traded goods and agricultural products need to be taken into account in trade negotiations to protect communities suffering from water stress.

2. Water security should become a core component of UK policy making. Government must assess the interrelationship between water, food and energy security in UK, informed by a systems based approach, with a view to achieving an optimal balance of aligned national policy.

3. UK industry must show leadership on global water security. Through their global reach, businesses must examine its supply chains and production processes to assess and reduce their water footprint. This should be a core component of their corporate and social responsibility strategies.

4. The regulation of the water sector globally needs to have integrated water resource management and sustainability informed by a systems approach at its core. The current disconnect between the provision of water and sanitation services and the wider water resource issues are all too apparent and it is essential to change the way the water sector is viewed and regulated.

5. The Government should bolster investment in the RD&D of solutions to global water security and work with the UK water industry to improve the development of the necessary models and data collection techniques to underpin international development policy.

6. The UK engineering institutions should ensure that their global memberships are appropriately equipped, through professional development, to apply a systems led approach to water engineering, incorporating the technical, geo-political, societal and ethical dimensions of the challenge. Engineers, along with all agencies involved need to engage with stakeholders to promote systems based solutions and with the public in general to support informed decision making in connection with water use.

References

1 Food, Energy, Water and the Climate: A Perfect Storm of Global Events? John Beddington CMG FRS Chief Scientific Adviser to HM Government
2 http://www.unep.org/DAMS/WCD/
3 UNDP Human Development Report 2006, http://hdr.undp.org/en/media/HDR06-complete.pdf p. 33
4 World Economic Forum, 2009
5 Global Water Partnership, Written Evidence
6 IWMI Annual Report 2005/2006, http://www.iwmi.cgiar.org/About_IWMI/Strategic_Documents/Annual_Reports/2005_2006/pdf/IWMI_AR_2005_2006.pdf p. 9
7 Coping With Water Scarcity – Challenge of the Twenty-First Century, UN Water 2007
8 World Economic Forum, 2009
9 http://maps.grida.no/go/graphic/increased-global-water-stress
10 IPCC, 2008; 57. IPCC, Meehl et al., 2007
11 Pacific Institute, 2009
12 IPCC, 2008
13 IPCC, 2008
14 Pacific Institute 2009
15 Powell et al, 2010
16 BBC ref, 2009
17 http://www.riverbasin.org/
18 Oregon State Uni research ref'ed in 19. UNESCO, 2003
19 UNESCO, 2003
20 Water in a Changing World, UN World Water Development Report 3, UNESCO, 2009
21 Molle and Berkhoff, 2006
22 UNESCO, 2003
23 World Bank, 2007
24 India's Water Economy, Bracing For A Turbulent Future, John Briscoe & IPS Malik, World Bank, 2006
25 India's Water Economy, Bracing For A Turbulent Future, John Briscoe & IPS Malik, World Bank, 2006
26 A report of Working Group I of the Intergovernmental Panel on Climate Change http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf p. 8
27 Pacific Institute, 2009
28 Water in a Changing World, UN World Water Development Report 3, UNESCO, 2009
29 Water in a Changing World, UN World Water Development Report 3, UNESCO, 2009
30 WWF, 2008; Indo-Gangetic Plain, in 13. UNEP, 2005
31 Al Hadidi 2005, ref'd in 13. UNEP, 2005
32 UNESCO, 2003
33 Fossil ground waters are historical sources of water that have been sealed in aquifers for a significant period of time, and are not replenished by infiltration.
34 Water in a Changing World, UN World Water Development Report 3, UNESCO, 2009
35 UNESCO, 2003
36 UNEP Global Environmental Outlook 2007 (ref 13.)
37 Water in a Changing World, UN World Water Development Report 3, UNESCO, 2009
38 Water in a Changing World, UN World Water Development Report 3, UNESCO, 2009
39 World Economic Forum, 2009
40 The Royal Society, 2009
41 de Fraiture et al., 2007
42 UNESCO, 2006
43 Water Footprint Network, "Water Footprint Manual, State of the Art", 2009
44 Water in a Changing World, UN World Water Development Report 3, UNESCO, 2009
45 Ian Barker evidentiary hearing
46 Pacific Institute, 2009
47 http://www.unesco.org/water/wwap/facts_figures/water_industry.shtml
48 World Economic Forum, 2009.
49 Pacific Institute, 2009
50 World Water Council, 2009
51 World Economic Forum, 2009
52 Taken from figure in 7. WWAP, 2009 which is ref'd as from another paper
53 Water in a Changing World, UN World Water Development Report 3, UNESCO, 2009
54 UNESCO, 2003
55 UNESCO, 2006
56 Molle and Berkhoff, 2006
57 SIWI, 2004
58 Thirsty Asia 2: How do we Respond to Peak Water" CLSA, Asia-Pacific Markets, 2010

59 World Economic Forum, 2009
60 World Economic Forum, 2009
61 World Economic Forum, 2009
62 UNDP, 2006
63 http://www.usaid.gov/our_work/environment/water/response_water_crisis.html, and other associated pages on their website looking at specific water security issues.
64 http://www.who.int/water_sanitation_health/glaas/en/
65 Charting our water future is a report of the 2030 Water Resources Group, 2009
66 WWDR3 Ch 15. Governing Water Wisely for Sustainable Development
67 UNESCO, 2003
68 Jo Parker, Evidentiary Hearing , 25/01/10
69 Environment Agency Managing Water Abstraction – Interim update 2, 2008
70 http://ec.europa.eu/environment/water/water-framework/index_en.html
71 London State of the Environment Report 2010 (http://www.environment-agency.gov.uk/research/library/publications/34083.aspx)
72 Chapter 12, Integrated Water Resources Management in Practice: Better Water Management for Development, GWP, 2009
73 UNESCO, 2003
74 World Development Report, 2010: Development and Climate Change report
75 World Development Report, 2010: Development and Climate Change report
76 World Development Report, 2010: Development and Climate Change report (same as for 74 and 75 etc)
77 World Bank, 2007; 16. World Economic Forum, 2010
78 UNDP, 2006
79 UNESCO, 2003; 15. UNDP, 2006.
80 World Economic Forum, 2010
81 http://www.unep.org/DAMS/WCD/
82 http://www.panda.org/what_we_do/footprint/water/dams_initiative/
83 World Bank. World Development Report, 2010: Development and Climate Change report
84 UNESCO, 2003
85 World Bank. World Development Report, 2010: Development and Climate Change report
86 see p144 World Development Report, 2010
87 ref World Bank. World Development Report, 2010: Development and Climate Change report
88 ref World Bank. World Development Report, 2010: Development and Climate Change report
89 ref: http://www.waterwatch.nl accessed 11 March 2010
90 More with Less: Agricultural Water Conservation and Efficiency in California by Heather Cooley, Juliet Christian-Smith and Peter H. Gleick, ICID, September 2008
91 http://www.unesco.org/water/wwap/facts_figures/water_industry.shtml#top accessed 11 March 2010
92 Feely, T. J., Skone, T. J., Stiegel, G. J., McNemar, A., Nemeth, M., Schimmoller, B., Murphy, J. T., Manfredo, L. (2008) Water: A critical Resource in the Thermoelectric Power Industry, Energy, 33, 1-11.
93 World Bank. World Development Report, 2010: Development and Climate Change Report
94 Council for Science and Technology (2009) 'A National Infrastructure for the 21st Century'
95 Institution of Civil Engineers (2009) 'The State of the Nation: Defending Critical Infrastructure'
96 Water for people and the environment - Water Resources Strategy for England and Wales, Environment Agency, 2009
97 Introduction to Desalination Technologies in Australia http://www.environment.gov.au/water/publications/urban/pubs/desalination-summary.pdf
98 http://www.csiro.au/files/files/ppcz.pdf
99 World Economic Forum, 2009
100 World Development Report, 2010: Development and Climate Change
101 The UN World Development Report (2009)
102 Watching water - A guide to evaluating corporate risks in a thirsty world (2008) Global Equity Research. J P Morgan
103 http://www.sustainableinnovation.org/, and www.waterfootprint.org
104 http://www.thecoca-colacompany.com/presscenter/nr_20081030_wwf.html
105 SABMiller and WWF, 2005
106 Hoeskstra et al., 2009
107 Chapagain and Orr, 2008.
108 Water Resources Group 2030, 2009
109 NERA, 2002. The Economics of Balancing Supply and Demand. UKWIR Report WR-03)
110 World Water Council, 2009
111 Birch et al., 2006
112 http://www.thameswater.co.uk/cps/rde/xchg/corp/hs.xsl/5392.htm
113 http://www.defra.gov.uk/environment/quality/water/strategy/pdf/future-water.pdf.
114 Chapagain and Orr, 2008.
115 UNESCO, 2003
116 Pacific Institute, 2009.
117 UN WWAP, 2009
118 Innovation for Sustainable Development: Case Studies from Africa. WWF, 2008
119 http://www.un.org/esa/sustdev/publications/africa_casestudies/lufumbu.pdf

Annex A - Working Group

Steering Group
Professor Peter Guthrie OBE FICE FREng (Chair)
Head of the Centre for Sustainable Development
University of Cambridge

Michael Norton MBE MICE FCIWEM
Managing Director, Water & Power
Halcrow Group Ltd

Mike Haigh FICE MCIWEM
Water Director
Mott MacDonald

Mike Woolgar MICE MCIWEM
Managing Director, Environmental & Water Management
Atkins

Jean Venables OBE FICE MCIWEM FREng
Chief Executive
Association of Drainage Authorities

Professor Roger Falconer FICE FCIWEM FREng
Director Hydro-environmental Research Centre
Cardiff University

Paul Horton
Director, International Development
CIWEM

Chris Binnie FICE FCIWEM FREng
Fellow of the Royal Academy of Engineering

Researchers
Dr Richard Harpin
Senior Vice President, Water & Power Business Group
Halcrow Group Ltd

Dr. Paul Wilkinson
Principal Water Resources Engineer
Halcorw Group Ltd

Lauren Mittiga
Senior Consultant
Halcrow Group Ltd

Robert Porter
Hydraulic Modeller
Halcrow Group Ltd

Staff
Beverley Parkin
Andrew Crudgington
Richard Ploszek
Katherine MacGregor
Jade Donovan
Andrew Wescott
Emily Beadon

Annex B

Evidentiary Hearings

Prof Tony Allan	SOAS
Ian Barker	WaterEnvironment Agency
Giulio Bocaletti	McKinsey London
Dr Sue Cavill	Engineers Against Poverty
Mr Ian Curtis	DfID - Hd of Profession Environment, Deputy Head of Climate and Energy Group
Dr Bruce Lankford	Senior Lecturer in Natural Resources, University of East Anglia
Dr David Lloyd Owen	Envisager
Jo Parker	Independent Consultant
Martin Walshe	Deputy Executive Secretary, Global Water Partnership
Dominic Waughray	World Economic Forum
Professor Howard Wheater	Imperial College London
Mr Sanjay Wijesekera	Head, Water and Sanitation Team, DfID
Prof Mike Young	University of Adelaide and CSIRO

Written Evidence

Dr Martin Griffiths, Issy Caffoor, Kerry Thomas and Perry Guess	Technology Strategy Board & the Environmental Sustainability Knowledge Transfer Network
Chris Perry	Freelance consultant & Co-Editor in Chief Journal of Agricultural Water Management
Bruce Horton	Water UK
Dr Alan MacDonald	Principal Hydrogeologist, British Geological Survey
John Wand	Water Research Councils UK
	CIWEM's Water Resources technical panel
Dr Guy Howard	Water & Environment Adviser, Climate & Environment Group, DFID
Ian Neal	Programme Manager, Excellent Development
Martin Walshe	Deputy Executive Secretary, Global Water Partnership
Dr A. J. Adeloye	School of the Built Environment, Heriot-Watt University
Melvyn Kay	UK Irrigation Association
Ian Barker	Water Environment Agency
Dr Sue Cavill	Engineers Against Poverty
Mr Ian Curtis	Head of Profession Environment, Deputy Head of Climate and Energy Group, DfID
Dr Bruce Lankford	Senior Lecturer in Natural Resources, University of East Anglia
Dr Rod Tennyson	Professor Emeritus, University of Toronto Institute for Aerospace Studies
	Engineers Australia, Water Engineering Branch
Enda O'Connell	School of Civil Engineering and GeoSciences, Newcastle University
Jodie Keane	Overseas Development Institute
Alan Jenkins	Centre for Ecology and Hydrology, Wallingford, UK
J K Banyard	
Ian Jenkinson	Chairman, Editorial Advisory Panel, Municipal Engineer

Details of the written evidence and evidence sessions can be found online at www.ice.org.uk/globalwatersecurity

Produced by:

The Royal Academy of Engineering

ice
Institution of Civil Engineers

CIWEM

FSC
Mixed Sources
Product group from well-managed forests and other controlled sources
Cert no. TT-COC-002794
www.fsc.org
© 1996 Forest Stewardship Council

Printed using vegetable based inks on paper from well-managed forests.

Engineering the future is a broad alliance of professional engineering institutions and associated bodies which represents the UK's 450,000 professional engineers.