Chapter 7 - Water Efficiency and Management

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Recommendations

- Funding bodies and other relevant organisations should:
  - fund research aimed at understanding the changes in the chemistry of the sewer flows due to increased precipitation intensity and to assess the impact of these potential changes on the efficiency of the wastewater treatment works to meet future WFD requirements.
  - fund research into the chemistry of flood flows and assessment of the potential impact of WFD substance consents on health at the time of flood events.
  - fund research that addresses changes in the chemistry of deposits on the catchment surface due to climate change and to assess their propensity to mobilise due to changes in the impact of urban storms.
  - fund research into constituents of dilute sewage that aims to suggest appropriate low cost, low energy treatment systems or alternative sewage strengthening technologies, as contingency.
  - fund an extensive review of knowledge associated with the implementation of sustainable water remediation measures from a chemistry viewpoint with a view to identifying shortfalls of knowledge and the potential for efficiencies and savings.
  - fund the research and development of materials for microfiltration of waters that can reduce energy costs per mega litre of treated water.
- RSC, Environment, Sustainability and Energy Forum (ESEF) and the WSF, to:

    - stimulate research to quantify the effect of the changes in operational and management strategies of sewerage assets and their potential impact on asset condition.
    - stimulate a programme of research to identify more clearly the interactions, fluxes and pressures associated with integrated water management from a 'chemistry' perspective.
    - form a working group to pursue the introduction of a universal statutory standard for sub-potable water.
    - form a working group to investigate overseas experience of 'fit and forget' formulations and dosing systems for disinfection of rainwater and grey water and their appropriateness for use in the UK.
- RSC, to form an expert working group on green product design, to advise on how to ensure sound and objective science is used in defining any legislation and regulations relating to the control of ingredients and formulation of household products. A particular issue is the current European debate on phosphorus.

Executive Summary

The chemical sciences are important for the effective and efficient use of available water resources by individuals and organisations. Whilst the efficient and sustainable use of water depends heavily on appropriate engineering infrastructure, domestic appliances and industrial assets and their use and management, the chemical sciences are strongly placed to enable the whole process.

Both the potable water distribution network and sewerage system can be regarded as long and complex linear chemical reactors. As with any chemical reactor, altering the inflows, outflows, pressures and temperatures can have a profound effect on the reactions taking place in the system.

In the case of potable water within the distribution network, current initiatives aimed at reducing both leakage and potable water demand could have a significant impact on the chemistry of flows within the network change.

The predicted variation in sewer flows resulting from climate induced changes in urban precipitation will undoubtedly have an effect on sewer chemistry. However, little detail is known at this stage about these changes and the full extent of their impact on the chemistry and management of downstream operations.

It is also expected that there will be complex interactions resulting from the combination of changes in water use and concentrations of micro-pollutants in sewage.

The economics of the current cost of water in the UK mean that rain water harvesting and/or grey water recycling systems do not have proven cost benefits for individual households. This scenario may change if security of supply issues, especially in the South and East of England, are factored in.

Membrane barrier processing techniques based on reverse osmosis or ultrafiltration will dominate local recycling schemes for grey water (ignoring rainwater storage and use). This is due to the multiple purification steps achieved by a single membrane process step.

In the UK, the current technologies for the use of rainwater and reuse of grey water have been installed by 'early adopter' enthusiasts motivated by environmental and/or social concerns. Further uptake requires recognition of this situation and the adoption of appropriate policies and programmes in order to move the technologies into more mainstream use.

Uptake of such systems would be assisted by the development of more robust 'fit and forget' dosing and control technologies and by the introduction of appropriate quality standards for sub-potable water.

Positive interaction between water efficient appliances and approaches and user/consumer is vital if they are to be effective.

There is a requirement to use techniques such as life cycle analysis where there is a need for objective scientific analyses for complex issues such as environmental impacts of household products and extra energy costs, contaminants and resource costs associated with rain and grey water use.

Introduction

This chapter covers the efficient and sustainable use of water from the outlet of the distribution reservoir to the point of entry to the waste water disposal unit. It covers the use of the water by domestic consumers, commercial, industrial and agricultural premises (Fig 1).

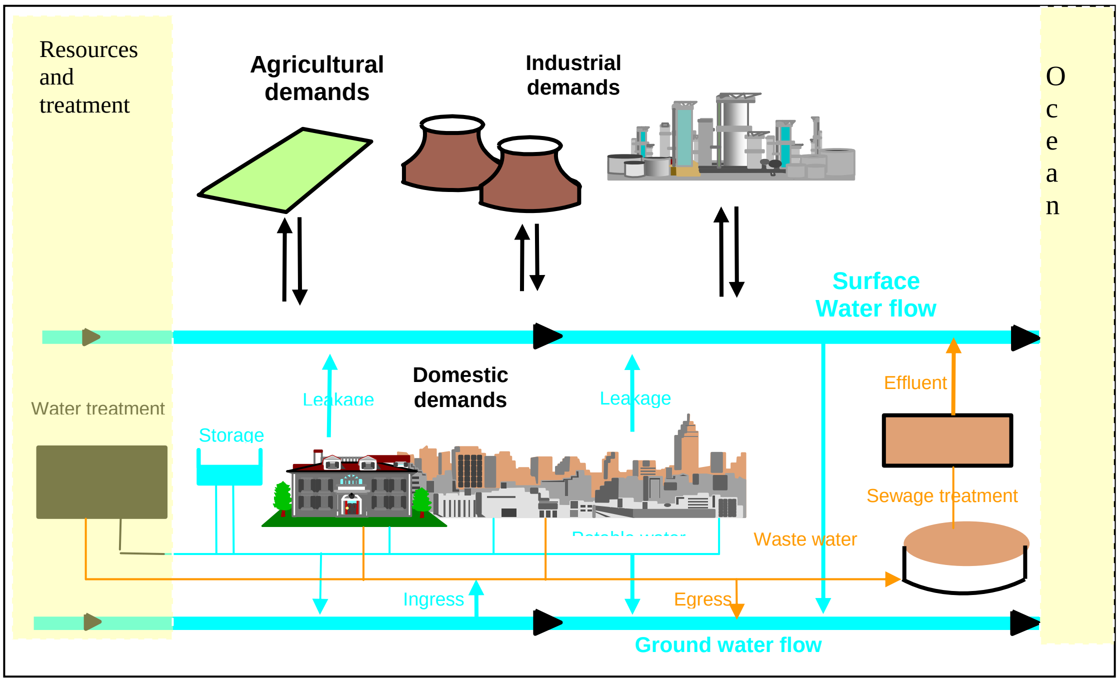

Figure 1: Scope

In the European context, the control and management of water quantity in all water sectors is a legal requirement [1] under Article 9 & 11 of the Water Framework Directive (Directive 2000/60/EC) in order to promote the sustainable use of water resources and to enhance the aquatic environment. The Water Framework Directive was adopted into UK law via the Water Environment (Water Framework Directive) (England and Wales) Regulations 2003 and the equivalent legislation for Scotland and Northern Ireland.

The overall aim of the Directive is to protect and enhance the ecological status of surface waters and groundwater throughout the European Union, with the unit of assessment being the 'river basin'. The Water Framework Directive regards improved water efficiency as an essential prerequisite to achieving these aims.

The purpose of the chapter is to examine the current and future chemical science needs for the effective and efficient use of available water resources by individuals and organisations. Whilst the efficient and sustainable use of water depends heavily on appropriate engineering infrastructure, domestic appliances and industrial assets and their use and management, the chemical sciences are strongly placed to enable the whole process.

The recent report on Water Management in England and Wales [2] from the House of Lords Science and Technology Committee comprehensively summarises many of the issues currently facing the management of water in England and Wales. Amongst its recommendations, the report highlighted several relating to the issues of water efficiency and management. The areas where the input from the chemical sciences would be particularly appropriate are identified below:

- Leakage from the potable water distribution network
- Water re-use and recycling
- Investment in long term research and development
- Public awareness, perceptions and education

Similar issues face Scotland and Northern Ireland. [3, 4, 5]

The House of Lords Report argued strongly for a twin track approach to address the problems facing water supply; an approach where measures aimed at increasing the efficient use of water by all customers and consumers was balanced with projects that simultaneously addressed the need for new supply side assets. This chapter by definition addresses the demand side issues of the efficient uses of water only. Other chapters in this report deal with the supply side.

Drivers and Barriers to Water Efficiency

Water efficiency and management take place against a complex background of issues and agendas that have evolved over the past 150 years. All of these impinge on and influence where and how the chemical sciences can contribute. Some issues can act as positive drivers to promote the efficient use and management of water. Others can act as negative barriers slowing down the uptake of ideas or technology that might enhance the more efficient use of water.

The current issues are summarised in the force field diagram in Fig 2. The thickness of the "field" lines gives a crude qualitative indication of the importance of that issue. These in turn start to inform not only where the chemical sciences can contribute but also starts to indicate where some of the priorities should lie.

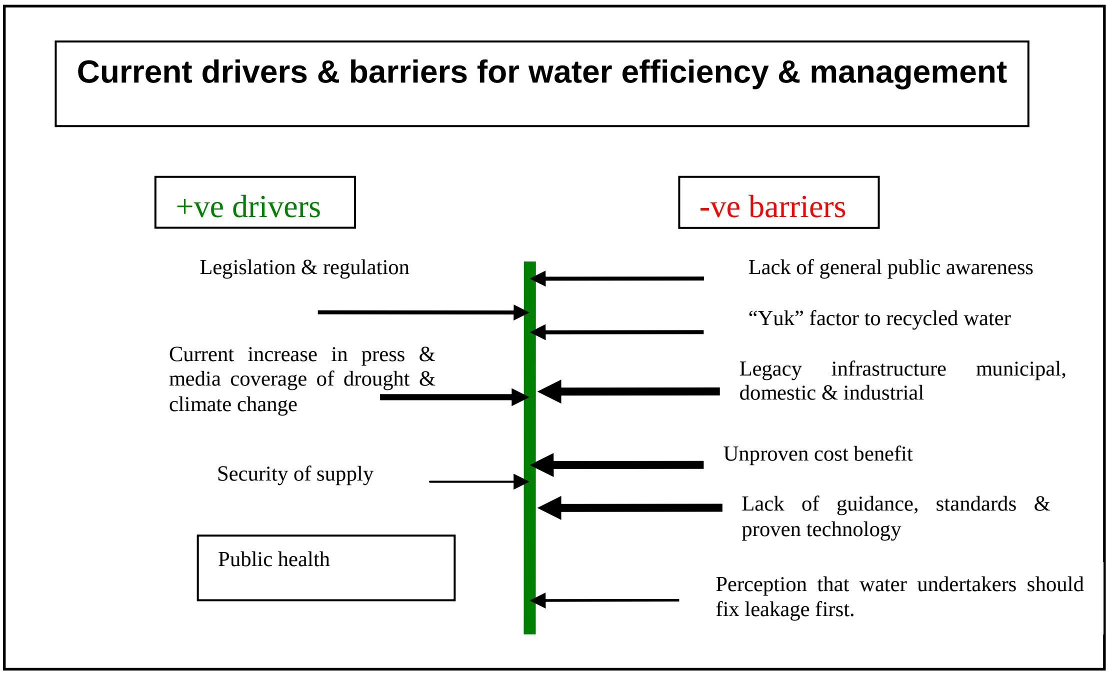

Figure 2: Drivers and Barriers

Legislation and regulation have long been recognised in numerous studies as the principle drivers for both individuals and organisations in the uptake of practices or technology associated with environmental issues. [6]

The most recent report (2004) for DEFRA on environmental protection spending by industry in the UK [7] reported that "the key drivers for capital expenditure were environmental regulation compliance (19%) and equipment upgrade (14%)". The report also comments that "the continuing increase of capital expenditure on water is likely to be driven by legislation, primarily IPPC regulations, which impose increasingly stringent environmental standards for water and wastewater treatment."

Similarly, in their discussion on domestic water efficiency, the House of Lords Report noted that water efficiency is not a selling point for a home and in some instances can even deter potential buyers. Thus "even if water efficient fittings do not cost any more than the regular kind, developers are unlikely to install them unless they are either compelled by regulations or tempted by incentives".

There are some specific requirements of the Water Framework Directive that will drive change. The Water Framework Directive states that surface and ground water conditions should achieve 'good ecological' status by 2015 with the construction of river basin management plans to propose a series of measures to improve or maintain the ecological status. The Directive proposed a timetable that stated that the characterisation of the river basins should be completed by 2004 followed by a consultation period with a view to the finalisation of river basin plans by 2009, to include a programme of measures to meet good ecological status for all waters by 2015.

In addition, Article 16 of the Water Framework Directive (see Decision No. 2455/2001/EC) proposed to identify 'dangerous substances' which present a significant risk to the aquatic environment. The list, commonly known as the List I or the 'Black List', includes "Priority Hazardous Substances" (PHSs) in respect of which discharges, emissions and losses to the aquatic environment should cease or be phased out.

Recommendation (1): Chemical scientists should continue to be involved in the consultations and drafting of appropriate legislation and regulation so that sound science is incorporated into legislation, regulation and codes of practice.

In particular, there is a need for RSC to contribute to the debate as to what in terms of the Water Framework Directive, constitutes "good ecological status" and how this may be measured.

Similarly, specific measures for the control of Priority Hazardous Substances have significant implications for UK Industry and there is an urgent need to identify the 'chemistry and interaction of these substances' in surface waters, sewage and groundwaters and their potential impact.

A more recent positive driver was the Summer 2006 increase in press and media coverage of the perilous state of the water supply in some parts of England. Although seasonal media coverage does not necessarily translate directly and immediately into action and changes in behaviour, it does at least get the issues into the public eye.

New data gathered by Waterwise from across the UK in July 2006 [8] would appear to support this view: Waterwise reported that overall water consumption had decreased even in areas not affected by water restrictions.

The chemical sciences can assist in the long and complex process of behaviour change with relevant education, whether of primary school children, the general public or ensuring that the chemical sciences issues of water efficiency are an essential part of the curriculum for the next generation of technologists and engineers.

The barriers associated with implementing greater water efficiency and management present the area of greatest opportunities for contributions from the chemical sciences.

The whole of the UK has an ageing water supply and drainage infrastructure and a brief examination of the amount of money that has been spent and is also planned for future expenditure gives an indication of the scale of the problems.

In England and Wales it was estimated that by the mid to late 1980s, it would cost £24 billion mostly to address the infrastructure maintenance backlog in order to meet the standards specified in certain European Community (EC) Directives. In the period 1989-2005 more than £50 billion was invested and it is predicted that a further £16.8 billion will have been spent by 2010. [2]

Scottish Water has similarly had to spend more than £1.8 billion between 2002-06 [3] and plans to invest a further £2.45 billion over the next four years in upgrading its assets.

In 2004 Northern Ireland Water Service announced that it intended to invest around £590 million to upgrade water and sewerage services in the period 2004 to 2006. [9]

A significant portion of the problems that result from the legacy infrastructure is leakage from the potable water distribution network. Leakage also forms part of issues relating to security of supply. The positive contribution of the chemical sciences through materials sciences, sensor technology and water quality to the range of issues associated with leakage is explored in depth in section AA.

There are some major predicated changes in precipitation from climate change which have significant implications for the chemistry of urban sewer flows, particularly in relation to the intensity and duration of storms. Section BB explores these and the related “knock on” effects downstream.

Water re-use and recycling has also been identified as an area that can make a significant contribution to the efficient use of water. For instance the Market Transformation Programme [10] using data from Envirowise suggests that potential savings of around 40% may be possible across all industrial process water uses and the Environment Agency around 30% [11].

In domestic situations, the Environment Agency [12] estimates that the amount of water required to flush household toilets could be met from household grey water. However, storage of, for instance, grey water or rainwater brings with it the potential for contamination; both microbiological and from oils, slimes, discolouration etc. It might also elicit what was described in the House of Lords report as the "yuk" factor; consumers may not find certain aspects of water re-use very aesthetic and might also associate its use with human waste.

The chemical sciences have a major role to play in all these aspects of water re-use and recycling. This may for instance be through disinfection and sterilisation systems or application of water purification technologies such as advanced oxidation or membrane technologies in industrial or municipal situations. Chemical scientists also have a significant role to play through the application of their knowledge and expertise in the development and good management of recycling and reuse systems. These issues are all explored further in Section CC.

Section AA Issues associated with the Distribution Network

<u>Distribution Networks</u>

The function of a distribution network is to convey potable water from the site of purification to the demand locations. There are statutory obligations on the water companies of England and Wales to provide water users in all parts of their geographical areas with an adequate supply, 24 hours a day, which meets regulatory and industry water quality standards whilst operating within a pricing framework. [13]

Following purification, potable water is dispatched to customers through a distribution network that consists of a number of components. These include storage devices such as service reservoirs and water towers; a network of pipes (trunk mains, distribution mains and service pipes); assisted by pumps, valves and other fittings that are necessary to operate and control flows and pressures within the system.

<u>What are the Challenges?</u>

The challenges are laid out in the regulatory requirements referenced above and summarising three of the most important points:

- Provide an uninterrupted supply to all customers at a minimum flow and pressure, 24 hours a day 365 days a year
- Provide a service that is good value for money
- The supply must comply with the stated quality regulations

The history associated with the responsibility for the provision of a potable supply, and the geographically different needs of domestic, industrial and agricultural consumers, has led to water distribution networks being developed in a piecemeal fashion to meet local requirements and subsequent changes in demands. Systems are therefore varied in size, materials of construction and operational complexity. These factors, and the historical emphasis on quantity rather than quality of supply, have generated legacy systems with numerous quality and hydraulic deficiencies, not least of which is losses due to leakage, that are exacerbated by rising demand and scarcity of resource.

Hydraulic and water quality performance in water distribution networks are inexorably linked. The size and material of pipes and fittings, the incoming water quality, and the supply demands on the network together promote hydraulic and water quality characteristics through a number of physical, chemical and biological mechanisms. These factors need to be considered simultaneously when examining sustainability and potable water distribution.

<u>Leakage</u>

In general, the UK water companies are proficient at ensuring their customers receive a continuous supply. However, during transit through the distribution network a significant proportion of the water entering is lost through leaks.

In the UK as much as 30% of distributed water is lost through leaks, with a national average of around 22%. Although leakage levels in England and Wales have dropped from a high of 5,112Ml/day in 1994-95 to 3,608Ml/day in 2004-05, [14] such levels of leakage could still supply about 24 million domestic users.

Recent leakage figures for Scotland indicate that Scottish Water had leakage of 973.46 Ml/day in 2000/01 rising to 1145.53 Ml/day in 2003/04 [15]. The Water Industry Commission for Scotland [4] has now introduced leakage targets for Scottish Water. Initial targets require Scottish Water to reduce its "high level of leakage" by a quarter over the next two years compared with estimated levels in 2004-05.

In 2001 the Northern Ireland Audit Office [16] reported that the loss through leakage was an average 253 million of the 692 million litres of water produced everyday (~37%). Reductions in leakage in Northern Ireland had not matched those achieved in England and Wales. An £80 million project to upgrade the ageing water mains was also announced in 2004 [9].

Across Europe, reported urban leakage rates vary greatly between 3% and 50%. [17]. Figure 3 shows urban leakage levels for a number of EC countries.

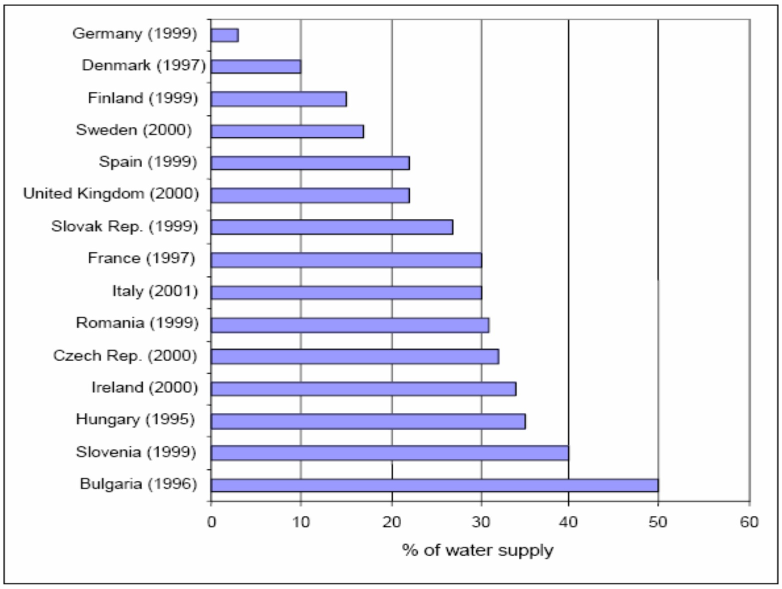

Figure 3: Estimated losses from urban water networks

With these volumes of water being lost there should be room for significant efficiency gains through leakage management and reduction.

Recent data from the Environment Agency for 2004-5 [18] provides another perspective on leakage in England and Wales. In the context of the components of the public water supply measured in Ml/day, total measured and unmeasured domestic consumption accounts for ~ 54% of the public water supply, with leakage and non domestic (industrial use) use each accounting for~ 23% of the remainder. Thus industrial usage and leakage account for broadly similar volumes of water from the public water supply. (Fig 4).

However, current UK leakage management practice is geared to achieving an "economic level of leakage" (ELL). ELL is defined as the point where the cost of identifying and repairing leaks is such that to go beyond this level would incur unacceptably high costs per leak repaired. The best practice principals in the ELL calculation are set out in the Tripartite Study report [19]. The calculations are complex and involve an estimate of the current leakage levels in networks. Estimates however, are difficult to obtain due to the number of variables and the lack of accurate data. However, it is worth noting that as the cost of energy changes, so the ELL will vary.

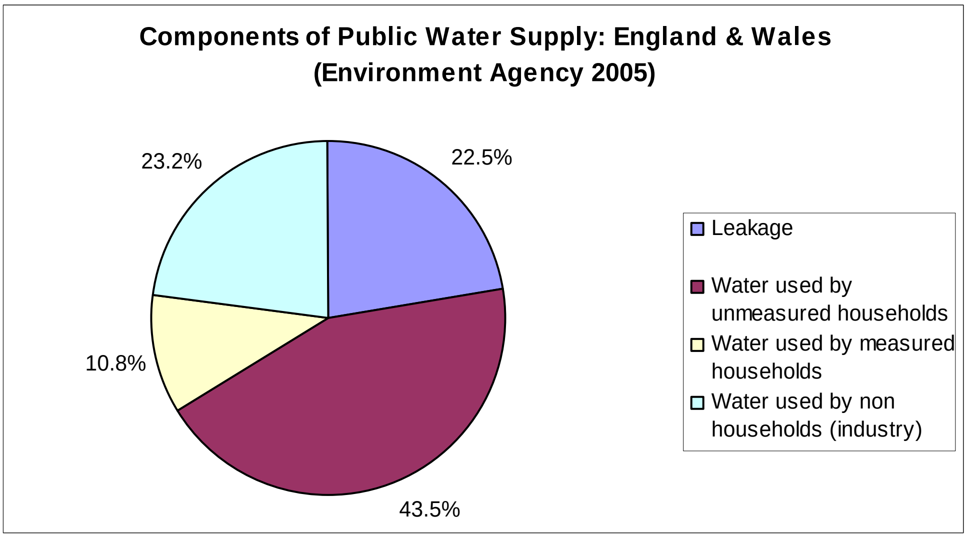

Figure 4: Components of Public Water Supply: England & Wales EA: 2005

Before leakage can be precisely estimated, accurate measurements of the volume of water entering the network and the volume used by all domestic and industrial users are required. However, leakage figures are built upon components which themselves are subject to potentially large estimation errors; accurate measurement is not possible because:

- Only ~26% of household supplies in England and Wales are metered
- Major industrial demand only is monitored
- All other components are estimates

When used in conjunction with pressure measurements, the availability of accurate demand data facilitates the use of mathematical modelling techniques to understand better how the estimated leakage volumes are distributed across the network. Mathematical modelling techniques can also be applied to determine how to optimise pressure management across entire water supply systems.
Gains may also be obtained by reducing the cost associated with detecting and locating burst mains. Flow and pressure data collected for leakage reporting tends to be a manual process riddled with inefficiencies and human error that result in leaks that are not obviously visible running undetected for extended periods (sometimes several months). Automatic data collection and computerised analysis can improve the burst detection process and provide a location to within an area inside a district metered area (DMA).

It is anticipated that if this research is continued the approach will be able to identify which pipe in the network has suffered a burst [20, 21].
Recommendation (2): The RSC promotes innovative research into appropriate sensor technologies to enable inexpensive flow and pressure measurement.

<u>“SmartPipes”</u>
In order to monitor and maintain network structural integrity, “smart pipes” or “intelligent infrastructure” are being developed by a number of groups. "Intelligent infrastructure” has attached or built-in components that are able to collect and transmit information about the state of the infrastructure to a central computer,

and in some cases receive back instruction from the computer, which triggers controlling devices." [22]

There are several definitions of a SmartPipe:

"...a SmartPipe is a fluid-conveying pipe with instrumentation for the determination of parameters describing the hydraulics and chemical nature of the fluid. ..., it has the ability to collect and transmit this information to a central computer for monitoring, optimization, and control." [23]

A SmartPipe can also be defined as a pipe that incorporates, at the time of manufacture, data transmission lines, instrumentation, and access ports for monitoring equipment". [24]

This technology could be used to capture flow, pressure, stress, strain and conductivity or resistivity data from distribution networks to support leakage management, and could be used to monitor the structural integrity of the pipes providing an immediate response to a developing leak or a burst.

A collaborative project between the University of Toronto and IPEX Inc. [25] to develop the Smart Pipe concept is already underway and a pipeline has been constructed to test system components, and preliminary designs for a Smart Connector have been produced (Fig 5).

Figure 5: SmartPipes™

Pipes made of composite materials like these can be embedded with sensors, making them into SmartPipes™

Work sponsored by the DOE-NETL Natural Gas Pipeline Infrastructure Reliability Program [26] has promoted the development of smart pipes that can detect and report structural damage and the location of the damage.

Support will be required from the chemical sciences to further develop these ideas into usable products or to support the transfer the technologies into the water sector.

Recommendation (3): RSC to promote collaboration between water engineers and scientists and materials and sensor engineers and scientists, with a view to specifying and promoting combined sensor and materials research and development, and transferring the technologies into the water industry.

Infrastructure Investment

The sustainability of a distribution network is dependent upon adequate investment in network infrastructure and repair and maintenance strategies. Distribution network infrastructure is currently managed via the concept of serviceability; that is according to current level of performance, rather than actual condition. Serviceability is something that can only be assessed over the long term, which is at odds with the 5 year financing cycle of the water industry.

OFWAT's policy is to take historic spending as a benchmark for investment which means stability in expenditure on renewing the infrastructure. However, it is inevitable that the scale of investment will have to rise significantly in the future, since the scale and complexity of the infrastructure has increased massively in the last 70 years.

Therefore, instead of seeking to suppress expenditure, it would be beneficial to identify those parts of the infrastructure that could be replaced now. Also, if the future is to downsize infrastructure due to control of losses, reduced consumer demand through education and transmission of water only for drinking the investment equations will look decidedly different. There is undoubtedly a need for investment in the integration of drainage and water use to improve sustainability [27].

Recommendation (4): RSC comment on Ofwat's consultation on periodic review periods in the context of the ability to make the necessary scientific and technological changes within the current review periods.

It is clear that with the correct drivers and initiatives in place the volume of potable water distributed could be significantly reduced but there are consequences for water resources and treatment, water quality, and sewerage and sewage treatment that must be considered.

<u>Water resources</u>

Percentage savings in demand will be reflected in the availability of more resources at times of low precipitation, but limited by resource storage capacity. Impounding reservoir levels should remain higher for longer periods providing natural treatments through mechanisms such as sunlight UV irradiation; removing colour and bacteria, and solids settling; decreasing loads on water treatment plants thereby allowing further savings on treatment chemical expenditure.

<u>Water treatment</u>

If there was a 40% decrease in demand for potable water, water treatment plants would be able to reduce their outputs by roughly the same amount, leading to a proportional reduction in treatment, operating and energy costs.

It may also allow a rethink on potable water production strategy as almost half the treatment capacity of a water company would no longer be required. This could facilitate more optimal use of resources and the mothballing or closure of facilities producing more cost savings.

Water quality

Potable water in England and Wales is of a very high quality. In 2001 the water companies in England and Wales carried out approximately 2.8 million tests on drinking water samples of which 99.86% passed and year on year improvement followed.

In 2003 new standards were introduced and in 2005 the compliance figure was 99.96% and as a whole the picture for 2005 is one of improvement from the baseline set in 2004 (the first year of reporting against the new standards). In 2005 for 18 parameters compliance was 99.99% or above. For a further 13 parameters it was between 99.95–99.99%. The three parameters with the lowest figures was the same as in 2004; iron 99.63% (mostly corrosion related), nickel 99.67% (groundwater related), and lead 99.76% (lead service pipes and internal plumbing related) [28].

If the flow in a distribution network is significantly reduced, whether by significant leakage reduction or more efficient water use, the probability of increased stagnation and the occurrence of associated detrimental water quality effects from mechanisms such as loss of disinfection residual, bacteriological re-growth, corrosion and sedimentation would be greatly increased. This would give rise to poorer water quality, customer complaints, and more regulatory water quality failures resulting in increased assessment, investigation, and remediation costs.

Novel disinfection methods

Chlorine is the most common disinfectant for potable water and has been used successfully for almost a century. Correct water treatment process control ensures that residual chlorine remains in the water as it travels through the distribution network to maintain bacteriological quality. However, because chlorine is very reactive, the residual decays with time due to reactions with bulk water components, pipe wall, network materials and deposits. The longer the water takes to pass through a network the lower the chlorine residual and many distribution networks often have no measurable disinfectant residual at their extremities. If leakage is significantly reduced this situation may be exacerbated and could give rise to public health problems.

To prevent this from happening, new disinfection methods or disinfectants that are longer lived and are as, or more, potent than chlorine could be developed. New disinfectant materials have already been studied. As far back as 1997 insoluble polymeric materials were evaluated for their efficacies in inactivating rotavirus in flowing water in a biocidal filter application [29].

A novel electrochemical reactor employing carbon-cloth electrodes was constructed for disinfection of drinking water in 1992 [30]. Continuous sterilization of E. coli cells was carried out over a 24 hour period by utilising the electrochemical reaction between an electrode and the cell which is mediated by intracellular coenzyme A. Sterilization of drinking water by using this reactor was successfully performed, demonstrating the potential of such a reactor for clean and efficient water purification.

The chemical sciences should support current and promote even more radical thinking and research about disinfection methods and practice. A novel example has been demonstrated by a Texan company, Lynntech, Inc. [31] who proposed a technology to reduce simultaneously the total organic carbon (TOC) content of a biological water processor (BWP) and control biofilm formation on water lines, surfaces and membranes within the water reclamation unit. The technology can be utilised on board spacecraft and within future planetary habitats. This technology is based on Lynntech's proprietary electrochemical on demand oxidiser generator, which does not require consumable chemicals.

Ultra Violet irradiation might be enhanced or replaced by emerging technologies such as Photocatalytic Oxidation. This relatively new process generates hydroxyl radicals ($OH^{ï}$) one of the most reactive free radicals and strongest oxidants) that degrade volatile organic compounds and kill micro-organisms. TiO_2 has been shown to be the most efficient photocatalyst for organic oxidative degradation [32]. Novel semiconductor pipe linings/coatings could be created that would allow hydroxyl radical generation within the network thereby maintaining a continuous dose of radiation lethal to bacteria and viruses without the need for chemical dosing.

To support disinfection, pipe materials with bactericidal properties could be further developed and utilised. Literature searches have identified that work in this area is ongoing.

Nano-fibre technology has been developed that when irradiated produce singlet oxygen that kills bacteria [33].

The surface of polyethylene slides nanocoated with silica and derivatized with long-chain poly(vinyl-*N*hexylpyridinium) becomes permanently bactericidal and has been shown to kill 90–99% of (both airborne and waterborne) wild-type and antibiotic-resistant strains of the human pathogen Staphylococcus Aureus [34]. The material was similarly lethal to strains expressing resistance to cationic antiseptics.

Bactericidal polymers exist that are used in contact lenses, dental materials and dressing materials for burns and wounds [35].

Recently, non-leaching, permanent, sterile-surface materials have been developed in which one end of a long-chained hydrophobic polycation containing antimicrobial monomers is attached covalently to the surface of a material, for example, cotton or plastic. The polymeric chain allows the antimicrobial moieties to permeate into, and kill, the cells of the pathogen. These sterile-surface materials kill both air and waterborne pathogens and are not susceptible to existing resistance mechanisms [36].

Recommendation (5): The RSC should promote the development of new disinfection processes and chemicals; not only for bacteriological water quality reasons, but also for wider public health benefits of disinfection without harmful by-products. Bactericidal materials research should be promoted to further develop or transfer the technology into the water industry sector.

Potable water complaints

The most common cause of potable water complaints is tainting as a result of the corrosion of iron mains. Although any discolouration caused by iron is unlikely to be harmful to health, it is aesthetically unacceptable and invariably generates complaints. If the residence time of water in a network is increased so is the propensity for corrosion and aesthetic water quality deterioration. Chemical agents such as phosphates can be introduced into the water supply to prevent iron dissolution but this is not the ideal solution.

A better alternative would be the introduction of corrosion free materials, and plastics have gone a long way to meeting this demand. However, they too have their problems. The internal pipe walls are rough and provide sites for chemical and biological growth. There is also some concern about “corrosion” of some plastics by oxidising agents such as chlorine causing them to become brittle, and the long term effect of pressure transients [37].

New Materials

If demand is to be dramatically reduced by a combination of domestic, industrial and leakage efficiencies, it may be necessary to consider downsizing distribution storage and network components. This would prevent stagnation and help to maintain or improve water quality and regulatory compliance. Such a shift in thinking would tilt the cost / benefit equation between refurbishment and replacement more in favour of replacement because of the lower cost of smaller components and reduced energy costs associated with pumping and network operation and repair and maintenance. Wholesale replacement would further improve water quality and reduce the costs associated with maintaining that quality increasing water supply sustainability.

New reservoir, pipe, pump, fixture and fittings materials could be developed to meet the need. Pipes, for example with very smooth internal surfaces for increased hydraulic performance, and to deter biological and chemical growths may be developed that can be laid in very long continuous lengths to reduce the number of joints to minimise background leakage; possibly even manufactured in situ. Alternatively, double skinned pipes might be developed that allow the internal diameter to decrease and increase as required to meet demand whilst minimising storage time in the network. These materials could have the bactericidal properties discussed earlier.

Recommendation (6): Water engineers and scientists collaborate with materials scientists in order to specify and develop optimal materials for leakage prevention and water quality maintenance.

Sewerage and Sewage Treatment

Reducing potable water demand and leakage has a knock on effect on sewerage systems in that many drains and sewers benefit from water ingress at times of low flow as it prevents septicity and sedimentation. This subject is dealt with in Section BB.

Section BB Issues associated with sewers & sewer chemistry

Drivers for future change

In respect of the current approach to the planning, design, installation, maintenance and operation of sewer systems, there are a number of global and national drivers for change. Recent studies [38, 39] identified the main drivers for change as:

1. Climate Change
2. Environmental and other Legislation (national regulations and EU Directives)
3. Land Use and Urbanisation including population demographics
4. Energy and Resource Use
5. Asset Condition, Performance and Serviceability

6. Science Engineering and Technology

The significance and impacts of the individual change drivers will vary in the short and long term and will also depend on the way in which socio-economic development advances in the UK and to a lesser extent, globally. To assess the impact of such drivers due to changes in socio economic and climatic factors it is necessary to complete scenario analyses. For the sewer system these are adequately reported elsewhere [40, 41] and here emphasis has been given to the requirements to better understand the chemistry associated with their impact.

The Need to Model System Substance Flows

From a chemistry viewpoint the approach has to recognise the need to model substance flows. The sources of such substances within the urban area are comprised of many different types of pollutants that are derived from many different sources. The latter range from diffuse sources associated with deposits on catchment surfaces through to a wide range of domestic inputs and those emanating from individual industry point sources. Pollutants to be considered include those that demand oxygen (BOD, COD), sediments (mainly TSS and aesthetics – in the UK defined as particles with dimension greater than 6mm in 2 directions), nutrients (usually nitrogen and phosphorous, heavy metals (usually copper, zinc, lead, cadmium, nickel, chromium), Organics (PAH's, PCB's, pesticides), bacteria, pathogens and viruses and endocrine disrupters.

Note, in the UK, the consents for sewerage discharges to receiving waters are based on aesthetics, BOD, ammonia and bacteria. However, the introduction of the Water Framework Directive will require a paradigm shift in the need for knowledge to assess impacts on ecology and habitat.

Recommendation (7): RSC reviews the instruments, sensors and analytical approaches and techniques that may be best applied to meet the needs of WFD.

The next sections discuss the impact of each of the drivers for change on such substance flows.

Climate change

In respect of climate change the primary parameter to influence the performance of the urban drainage system is a change in urban precipitation. There are two identified changes that may significantly influence the chemistry of urban sewer flows. Firstly it is predicted that, in some parts of the country, there will be increases in short duration storms with high intensity.

Short duration storms with high intensity

Higher intensity summer storms will have the impact that there will be more rapid surface runoff from the catchment surface and that such increases in intensity will result in the more rapid pollution washoff from catchment surface. Models to predict the build-up and subsequent release and transport of substances deposited on urban catchment surfaces have seen some success [42, 43] but the potential for change under different socio-economic and climatic scenarios is unclear, both from unknown differences in the characteristic of the pollutants deposited on the catchment surface and in the different mobilisation and transport strategies that ensue due to changes in preciptation.

Recommendation (8): RSC attempts to address changes in the chemistry of deposits on the catchment surface due to climate change and to assess their propensity to mobilise due to changes in the impact of urban storms

Increases in the intensity of urban storms will also result in a more rapid build-up of the flow that enters the sewer system with an in-sewer flow hydrograph that is much more peaked. The peakedness of a storm, usually defined as the ratio between the peak flow and the average flow over the duration of a storm, will therefore increase.

Previous research [44] has shown that the peakedness of a storm influences significantly the quality of the sewer flow and, in particular, increases the magnitude and load of the first foul flush – a phenomena that is observed to occur in most sewer systems that are combined, i.e. the pipes in the system convey both the domestic and industrial effluents and the rainfall-runoff from the catchment surface. The first foul flush occurs early in the storm event and it has been shown that some 80% of the total storm pollutant load may be observed to pass through the system within the first 50% of the storm flow.

Previous research has highlighted that the first foul flush phenomena is based on a build-up of sewer sediments, in layers on a daily basis during dry weather, and that when the storm flow increases to meet a critical erosion threshold, the deposited sediments are eroded and transported. The magnitude of the first flush has been shown to be a function of the sewer size, the diurnal pattern and characteristics of the dry weather flow, the peakedness of the sewer flow and the volume of sediment available to transport.

Future scenarios of increase rainfall intensity will see an increase in the flush load to treatment and hence in a reduced treatment efficiency at the works. Current research has addressed the need to meet the requirements of current legislation and consents but in terms of substances identified within the WFD there is a massive shortfall of knowledge.

Recommendation (9): There is a need to understand the changes in the chemistry of the sewer flows due to increased precipitation intensity and to assess the impact of these potential changes on the efficiency of the WwTW to meet future WFD requirements.

The hydraulic capacity of the existing sewer system may also be compromised due to the increased magnitude and volume of the sewer flow. This will increase the potential for surface flooding with an increased opportunity for sewer sediments and the contaminants they contain to cover catchment surface and to increase health impacts. Current research FRMRC is attempting to examine the impact of pathogens on health but little is known about the chemistry of the other substances and as to how these impact on health.

Recommendation (10): RSC examines the chemistry of flood flows and assesses the potential impact of WFD substance consents on health at the time of flood events

Longer duration winter storms with increased storm volume

The second identified precipitation driver relates to the potential for changes in the characteristics of winter storms. These have the predicted potential to be of longer duration and to have a corresponding increase in the volume of rainfall. Such storms have the potential to increase surface runoff due to the catchment surface being wetter, perhaps saturated, as the storm progresses over the duration of the event and due to the fact that the infiltration capacity of the catchment surface is much reduced.

There are several impacts of such storms:

- Increased groundwater level
- Increased infiltration inflow
- More dilute dry weather flow
- More dilute flows due to storm events (reduced first flush)
- Reduced efficiency of treatment works – continuous operation with dilute dry weather flow and storm flows
- More frequent spills from sewers to receiving waters as sewer system capacity is reduced due to fuller flows and available storage capacity reduced
- Longer retention times of dilute sewage

From a chemistry viewpoint the major interest relates to the treatment of dilute sewage, and, more especially, the desire not to do it.

Recommendation (11): RSC to learn the constituents of dilute sewage and to suggest appropriate low- cost, low-energy treatment systems or alternative sewage strengthening technologies, as contingency.

Sustainable Remediation Measures

UKWIR [45] identified responses to address the impact of climate change on the performance and operation of the urban drainage system. These were linked into the following categories:

1. Manipulation of the inputs to the sewer system –the potential for manipulation of dry weather and wet weather inputs, i.e. local storage, disconnection, rainfall (storm) and foul flow separation, local storage, water re-use and water recycling
2. Optimisation of existing infrastructure and smart system management; with a focus on real time control and the introduction of better management and operational strategies.
3. Using new or emerging technologies to reduce or eliminate the specific impacts of substances that currently issue for sewer systems into receiving waters, for example local treatment at the discharge points for the priority substances
4. Institutional arrangements, the role of the planning process and influencing future environmental legislation.

Chemistry plays a key role in the development of appropriate and cost effective solutions to address the potential for change, and the impact of each individual response is now discussed

<u>Manipulation of the inputs to the sewer system</u>

There are now many techniques that may be used to control the inputs to new or existing urban systems and to accommodate or reduce the impact of climate change. [46] defined several concepts to address this issue:

- Water conservation – doing less with less
- Water efficiency – doing more with less
- Water sufficiency – enough is enough
- Water substitution – replace water with something else

- Water re-use, recycling and harvesting – a potentially virtuous circle

To address these concepts there are a number of specific measures that may be adopted. Such measures are usually appropriate for application to an individual household or to a local community. Typical approaches include:

- Green roofs
- Rainwater harvesting systems, including re-use
- Disconnection
- Under driveway storage cells
- Infiltration Systems
    - Soakaways
    - Trenches
    - Porous pavements
    - Swales
- Local Sustainable Urban Drainage systems
    - Small ponds
    - Small wetlands
- Re-cycling of grey and blackwater
- Local sludge treatment systems

Current research is extensive and attempts to address both the quantitative and qualitative aspects of system performance.

<u>Sewer Separation</u>

At a catchment scale there is the potential to promote Sewer Separation, whereby the existing combined sewer system is converted into two separate systems, one for foul flows (domestic and industry) and one for storm flows. There are many examples where this is being attempted worldwide, for example Holland, but generally it is considered infeasible in large densely populated UK urban areas due to complexity and lack of information on the locations of all the different utility types of buried infrastructure.

The use of separate systems in is perfectly feasible in **New Developments** and is widely practiced throughout Europe. When such systems, are linked directly to local storage and re-use and recycling systems, as described above, it has been shown [47] that there is the potential for systems to have a self sufficient water cycle.

One of the impacts of the partial inclusion of such technology within existing systems is that less rainwater will enter the existing sewers in the vicinity of properties, and that this, together with the potential for reduced water inputs from household water saving devices, will result in the opportunity for the solids in blackwater to become stranded within local pipes, resulting in increased sedimentation and the potential for blockage. This affords the opportunity to examine the current design of our foul water systems, for example, the wider introduction of vacuum systems.

From a chemistry viewpoint the majority of these systems have been constructed within the last 10 years, more probably the last 5 years and hence there is a clear lack of understanding concerning the longer term performance of such systems, including the impact of existing operational and maintenance strategies on system performance. Attempts have been made to estimate substance flows and such approaches will be essential in the UK to meet the needs of the WFD and its sister Directives. There is a clear need therefore to better understand the chemistry of such processes.

Recommendation (12): RSC completes an extensive review of knowledge associated with the implementation of sustainable remediation measures from a chemistry viewpoint with a view to identifying shortfalls of knowledge and the potential for efficiencies and savings.

Optimisation of existing infrastructure and smart system management

It has been common practice in the UK to provide the enhanced opportunity to store combined sewer flows in many different types of storage structure in the form of rectangular, circular and shaft tanks or to utilise any spare capacity in the existing sewers by providing some form of sewer flow attenuation. The impact of such measures is to increase the requirements for pumping and to increase the retention time of the sewage within the system, with an increase in the septicity potential and the generation of odours.

However there is the potential to get smarter with the way in which existing sewerage assets are operated and managed. There are new opportunities for in-sewer treatment and for the real time monitoring and control of our underground assets. This is particularly so due to the developments in sensor technology, wireless communications and robotics.

There are also opportunities to better understand the condition of these assets and as to how this condition changes with time, particularly in the light of new operational and management strategies. However, it has to be said that the condition of our existing assets is poorly understood. Such deterioration is very much linked to understanding system chemistry and as to how the chemistry of sewage changes with time and temperature within these controlled environments, and as to whether this chemistry accelerates asset deterioration or otherwise. Little is understood and there is large uncertainty in existing models.

Recommendation (13): RSC stimulates research to quantify the effect of the changes in operational and management strategies of sewerage assets and their potential impact on asset condition.

New or emerging technologies to reduce or eliminate the specific impacts of substances

There has been significant investment to develop new end of pipe solutions to remove and treat specific substances for environmental protection. Such technologies are considered elsewhere within this report.

Institutional arrangements, the role of the planning process and influencing future environmental legislation

Worldwide there is a move towards integrating the whole water cycle without distinction between water supply, water use and wastewater disposal – **integrated water management (IWM)**, including urban flooding. Although this chapter has identified that it is feasible to identify good practice and the needs for research associated with the individual components of the system, there is now a need to integrate all aspects of water within an holistic Institutional, planning and legislative framework.

This involves the integration of all Institutional and stakeholder activity and within the urban area a series of pilot studies are about to commence to address these issues [48]. The 'chemistry' of this integrated water management (IWM) framework is poorly understood and the desire for better understanding will stimulate, promote and influence future policy.

Recommendation (14): RSC stimulates a programme of research to identify more clearly the interactions, fluxes and pressures associated with integrated water management from a 'chemistry' perspective.

Section CC Non potable sources of water, water re-use and recycling

The demands on the water distribution network were identified in Fig 4 in section AA and showed that two of the most significant contributions are metered and non metered domestic use (54%) and industrial needs (23%). This section explores these areas in more detail and more importantly examines ways in which these could be reduced.

How much water gets used by whom and for what?

<u>Domestic</u>

Domestic demand for water accounts for around 54% of the public water supply with an average consumption of about 150 l/day per person. As well as predictions that per capita water consumption will increase, there is also the demographic fact that the number of one person households will increase. These issues are covered more fully in chapter 2. The House of Lords report felt that the main focus for water efficiency should lie in domestic households rather than in industry where water consumption is already reducing.

The greatest percentage of water used in households is used for flushing toilets (35%) [12] (Table 1). It is this aspect of domestic usage along with outside uses (6%) that particularly lend themselves to water re-use and recycling. Thus savings of potable water of around 40% of domestic use (equivalent to 22% of total public water supply) could be made.

Household Water Use	**Use (%)**
Wash basin	8
Flushing toilets	35
Dishwasher	4
Washing machine	12
Shower	5
Bath	15
Kitchen sink	15
Outside use	6

Table 1: Household Water Use

There are many things domestic consumers can do to minimise wastage in and around the home about which they should be better informed than they currently are. Examples are:

- Choosing the most water efficient household appliances, e.g. washing machines and dishwashers

- Installing low or dual flush toilets which use a third less water than average (6 litres per flush rather than 9) or put a 'sava-flush' or 'hippo' in the toilet cistern
- Taking a quick shower uses a third of the water of a bath; however, power showers can consume more water than a bath
- Installing a water butt to collect rainwater for garden watering rather than using a hosepipe from the mains supply (which can use up to 1000 litres per hour)
- Growing garden plants that can tolerate drought and don't need regular watering.

Recommendation: The RSC helps to promote public and academic awareness and education programmes about all aspects of the water cycle, the detrimental environmental and economic effects of wasting water resources, and making informed decisions about domestic and industrial water use.

Recommendation: The RSC actively promotes the collaboration between water companies, industrial users, academia, and chemical sciences to optimise industrial water use.

Recommendation: The RSC become involved in political, social and industrial discussion about incentives to reduce water use.

<u>Commercial and Institutional</u>

Commercial and institutional water usage covers a wide variety of establishments from offices to schools and hospitals, defence establishments and prisons. Such establishments that are not offices are frequently termed "non households". Although such usage might primarily be viewed as domestic rather than industrial in nature, the scale of usage is such that it can and does equate to a commercial process and thus can lend itself to a significantly different approach.

<u>Industrial</u>

Industrial water use covers the greatest breadth of uses. Appendix 1 shows the amounts of water used by top industrial water users in Scotland in 2004 and serves to illustrate some of the diversity of usage and requirements. For some industrial users, water is the principle component of their product (e.g. soft drinks and mineral water) and the water used has to be by definition of potable quality. Other customers such as fish farmers also use large quantities of water but do not consume it. In this industry it is any materials that are used in the fish farming process that are the issue as they influence any downstream use and/or treatment requirements.

Malt distillers get the bulk of their water by direct abstraction and indeed the characteristics of that water can be a major factor in distinguishing their product from others in a similar area. Such abstractions can also have a significant localised impact on the water course both in terms of the level of abstraction and any subsequent discharge.

The electronics industry presents yet another facet of water quality requirements and recycling potential where part of the requirements is for ultra pure water.

In terms of the volume of potable water used by industry as a whole, section AA above identified that in England and Wales in 2004-05 industrial usage accounted for around 23% of the public water supply, where "industry" encompasses the whole range of properties not occupied as domestic i.e factories, offices, and commercial premises, cattle troughs. It also includes properties containing multiple households.

Fig 6 shows the breakdown of water supplied by the then Water Services in Northern Ireland [49]. The report states that there is no information available on the direct abstraction of water. It further comments that although domestic abstraction is thought to be minimal, industrial abstraction could be more significant.

Table 2 gives some examples of potential process water savings in some high water using industries. Thus although domestic water use may account for the bulk of the mains water supply, there are significant potential savings that could also be achieved by industrial users.

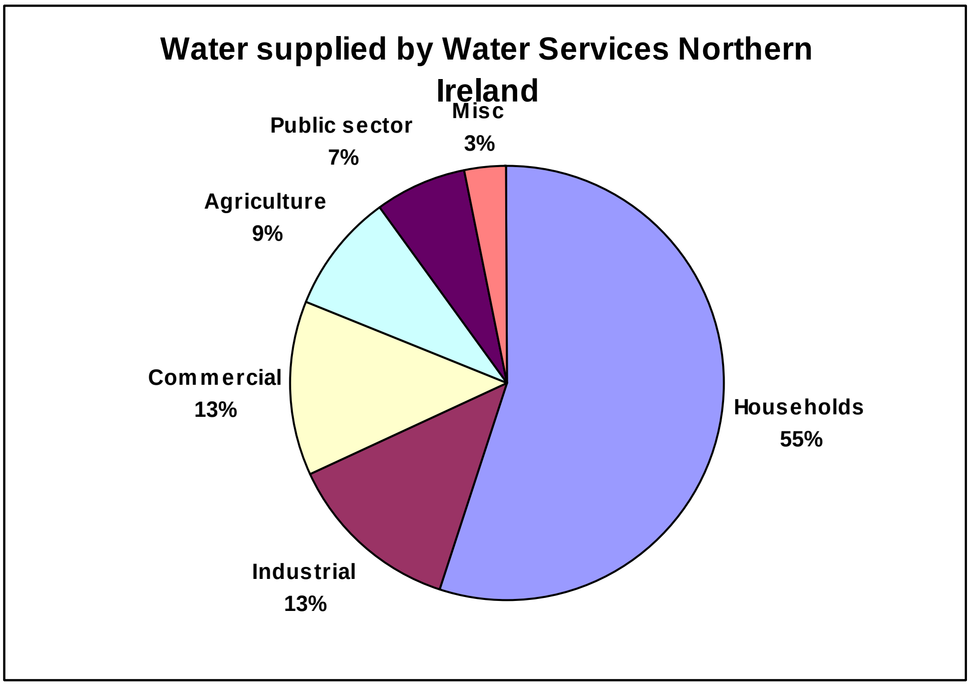

Figure 6: Water Supplied by Water Services Northern Ireland

Industry	**Potential process water savings (%)**
Soft drinks manufacture	>10
Brewing	>90
Paper & board manufacture	40
Printed circuit board manufacture	75
Speciality chemicals	50
Metal finishing industry	75
Textile dyeing & finishing	30

Table 2: Potential Process Water Savings (source: Defra Market Transformation Programme 2006 [10])

It should be noted that there are also embedded energy savings when water consumption is reduced: from the reduction in energy required to produce water, pump it around and treat resultant waste waters. There will also be a reduced requirement for all the other material resources used in the production of potable water and the treatment of waste waters.

Fig 7 gives an indication of the magnitudes of potential savings in potable water use that could be made if the savings and reduction in leakage identified elsewhere in this chapter were realised.

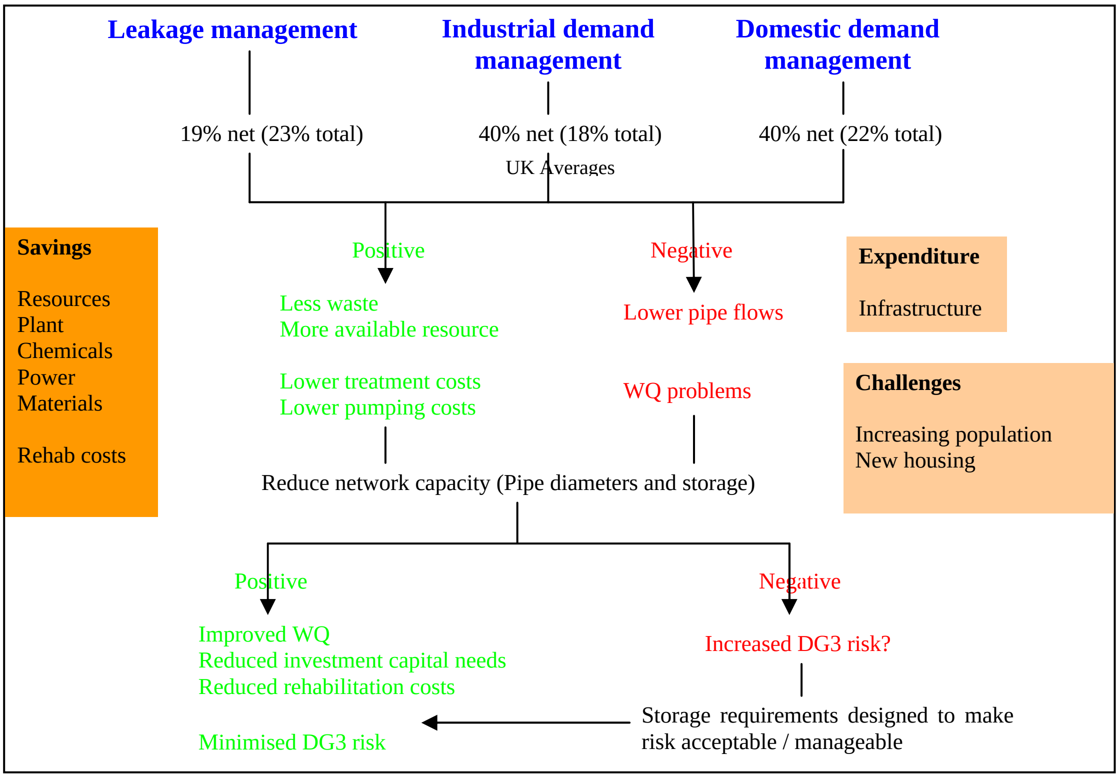

Figure 7: Potential Demand Reductions from applying "Sustainable Use of Water Principles

<u>Rain water and grey water</u>

The section above has identified what water is typically used for and by whom. This section addresses where the chemical sciences can contribute to the efficient use of the water that is used. As noted in the introduction to this chapter, much can be achieved through the application of appropriate engineering and efficient water using equipment. This section concentrates on where the chemical sciences can enhance and enable such infrastructure.

The concepts of recycling and reuse are closely linked with the definitions and requirements of non potable sources of water. In the context of this chapter, the sources of non potable water that are discussed for domestic, commercial and institutional and industrial reuse situations are rain water and grey water.

Rain water is typically collected from roof guttering, permeable paving etc and its end uses are activities such as toilet flushing, garden and grounds watering, vehicle and yard washing and laundry. The Environment Agency [50] estimated that on average around 46% of household consumption of mains water in England and Wales could be met by using rain water rather than mains water.

Grey water is defined as mains water that has previously been used for activities such as baths, showers and wash basins. It does not include mains water that has been used for clothes washing, dish washing or toilet flushing (termed black water). End uses for grey water include toilet flushing, vehicle washing and other appropriate industrial processes.

There are currently no official standards for quality for the use of either rain water or grey water. The Environment Agency [51] noted that although the Water Supply (Water Quality) Regulations 1989 (Amendment) 1999 specify the quality standards for drinking water, these standards are considered by experts to be too strict to apply to non-potable harvested rainwater. The standards used for bathing waters may be more appropriate.

The Environment Agency [50] quotes the "guidance only" standards from the "Buildings that Save Water" project for harvested rainwater (Table 3).

Similarly guidelines for the use of "reclaimed water" in New South Wales [52] state the microbiological requirements for consumer use and the corresponding uses for the reclaimed water (Table 4). There are also intermediate standards.

Evidence given to the House of Lords Report suggested that the lack of appropriate standards for sub-potable water was limiting the use of water recycling in the UK. Subsequently, one of the recommendations from the Report was that the Government should "consider, as a priority, the feasibility of introducing a universal statutory standard for sub-potable water intended for re-use".

	Class A	**Class B**	**Class C**
Applications	**Vehicle Washing Sprays**	**Drip & sub-surface irrigation**	**WC flushing(no taps)**
Water Quality guideline total coliforms cfu/100ml	10	1,000	1,000
Test criteria total coliforms cfu/100ml	1	100	100

Table 3: "Guidance" Harvested Rainwater Standards: Environment Agency

Disinfection level	**Uses**
Coliforms < 2.5 in 100ml geometric mean over 5 consecutive samples <25 in 100ml (in 95% of samples)	Residential garden irrigation Toilet flushing, car washing & similar outdoor uses, firefighting Water bodies for passive recreation Ornamental water bodies

Table 4: New South Wales reclaimed water disinfection levels

There is no mention of statutory standards in any context in the Government response [53] to the House of Lords report.

Recommendation (15): Chemical sciences pursue the introduction of a universal statutory standard for sub-potable water.

Rain water may only require a minimal level of treatment such as filtering where it is used for activities such as garden and grounds watering or toilets. However if it is used in a spray application such as washing vehicles then some disinfection may be judged appropriate.

It is usually essential that grey water is disinfected. Even after disinfection, most references state that grey water can only be stored for up to 3 days.

The means of disinfection required for a source of rain water or grey water is one of the areas where the chemical sciences have a role to play.

Disinfection of potable water supplies is well documented [54]. Where disinfection utilises a chemical means of disinfection it usually uses one of the following chemistries:

- Free Chlorine
- Chloramines
- Chlorine dioxide
- Hypochlorite
- Iodine
- Ozone
- Silver or Copper

In addition, Bromine chemistry is used extensively for the disinfection of swimming pools, although not for potable water supplies.

UV disinfection is not generally possible on grey water systems because of turbidity. However it can used on a rainwater collection system where there is a potential for overflow for instance, into a surface water drainage system where the use of chemical disinfection would generally be inappropriate.

Disinfection of rain water or grey water is typically achieved using chlorine or bromine based disinfectants in either liquid or tablet form. The CIRIA 2001 Reports [55, 56] detail the issues particularly associated with the use of such systems for rain and grey water systems.

The aspect of dosage control is very important. Grey water systems require good dosage control, proper maintenance and some understanding of what the system is aiming to achieve in order to prevent any risks to health.

A UK study by Thames Water [57] of a domestic greywater recycling system in five new build houses used Bromine tablets to disinfect the reclaimed water. The study found that there were large variations in Bromine concentrations and sometimes high levels of Bromine resulting in a "bleachy" smell in the homes and high levels of free Bromine. The authors attributed the problem to the "lack of control of the dosing system". The authors also pointed out that "there is a potential risk of the release of toxic off-gas (elemental bromine) if anti-scalant chemicals were used in the toilet bowl".

There are potential health implications if disinfection systems are not working properly. Similarly if simple maintenance tasks are not carried out, then filters can block and pumps fail. These points were also noted in CIRIA's (Construction Industry Research and Information Association) 2001 Reports [55, 56]and Defra's Market Transformation Programme [58].

This suggests a need to develop better dosing and control systems that are "fit and forget". It would be worthwhile to investigate the experiences and practices of countries such as Germany, Japan and Australia where the use of rain water and grey water systems are far more prevalent and accepted and where appropriate legislation exists.

Recommendation (16): Chemical sciences investigate in detail overseas experience of "fit and forget" formulations and dosing systems for disinfection of rain water and grey water and their appropriateness for use in the UK.

Realistically however in the UK at the moment, the price of potable water is low when compared to other European countries and only some 26% of domestic users in England and Wales have a metered water supply. Thus individual household rainwater or grey water reuse systems are not economically attractive especially if retro fitted. Householders can contribute in the short term by watering gardens using water collected from using rain water butts and by purchasing and using water efficient devices rather than investing in expensive re-use systems which also have ongoing maintenance requirements.

A recent life cycle analysis of domestic water use in the United States [59] has added further emphasis to this latter point. This study concluded that "water use and consumption within buildings have a much larger impact on resource consumption than the water and waste water treatment stages of the life cycle". The authors argued that this is because the amount of energy required during the domestic water use life cycle is greatest within buildings from heating water. Thus minimising the wastage of heated water can make the greatest overall contribution to reducing the total environmental impact.

Larger scale new housing developments or commercial/institutional buildings mostly have a metered water supply thus making the use of recycling systems more economically attractive. Access to a shared infrastructure and ongoing maintenance programmes can also contribute to making the running of these systems more viable. In all scenarios, acceptance by the users is crucial for success.

Water Framework Directive and household products

The Thames Water study discussed above raises the point that if such systems become more widespread in the future, then this may require some reformulation and/or relabelling of household products to take account of potential situations such as chemical reactions with household disinfection systems.

Similarly CIRIA notes that greywater systems that use halogen based disinfectants "will increase the formation of by-products such as chloroamines, bromoamines and trihalomethanes, which cause environmental concern".

Water recycling and overall water usage for 'domestic' (cleaning, washing and toilet flushing) is influenced by the chemical composition of the consumer products. The elimination of phosphate based detergent and improved biodegradability has influenced sewage processing.

Water and energy consumption has also been driven down by manufacturers, legislation, and consumer pressure; facilitated by improved detergents and enzymes in soap formulations. Lower temperatures and water volumes may lead to increased deposition of solids and free oil and grease (FOG) in local sewage systems due to higher concentration and earlier solidification. Enzyme activity may also continue beyond the local drain, affecting recycling or sewage digestion. Biodegradable components may also lead to increased microbiological activity.

Bleaching compounds are also changing from chlorine and perborate formulations to percarbonate chemistry, reducing possibilities for toxic by-products. Chlorine bleaches and disinfectants will probably continue in toilet cleaners due to high anti-microbial activity and persistence, however the lower usage and 'Black water' application removes these from local recycling schemes.

The development of household products is also important in relation to the requirements of the Water Framework Directive and "good ecological quality". For instance household use of detergents is ubiquitous and the biodegradability and phosphate content of detergents have to be considered in this context.

The biodegradability of detergents is controlled by the UK's Detergent Regulations 2005 (Statutory Instrument 2005 no: 2469) which implement the European Regulations 648/2004 on detergents. The Commission must also review and, if justified, present legislative proposals to extend the biodegradability rules by April 2009. [60]

However, one of the implications of the Water Framework Directive is further control of nutrients in waste water streams. The European Commission must evaluate the use of phosphates in detergents by April 2007 and propose legislation with a view to their gradual phase out or restriction if necessary. [60]

The sources of phosphate into European surface waters are shown in Fig 8. [61], though it should be noted that there can be a wide variation in loading at a catchment level.

Table 5 gives estimates of the percentage contribution to total phosphate by source in waste water from an OFWAT regulated water undertaker [61] and indicates that domestic sources rather than trade effluent are the most significant contributor. OFWAT also comment that where no actions for reducing the amount of sodium tripolyphosphate in phosphate containing detergents have been undertaken, then the amount of phosphorus in waste water that can be attributed to detergents can be "as high as 40%".

Thus agricultural sources account for around 50% compared to detergents at 11%.

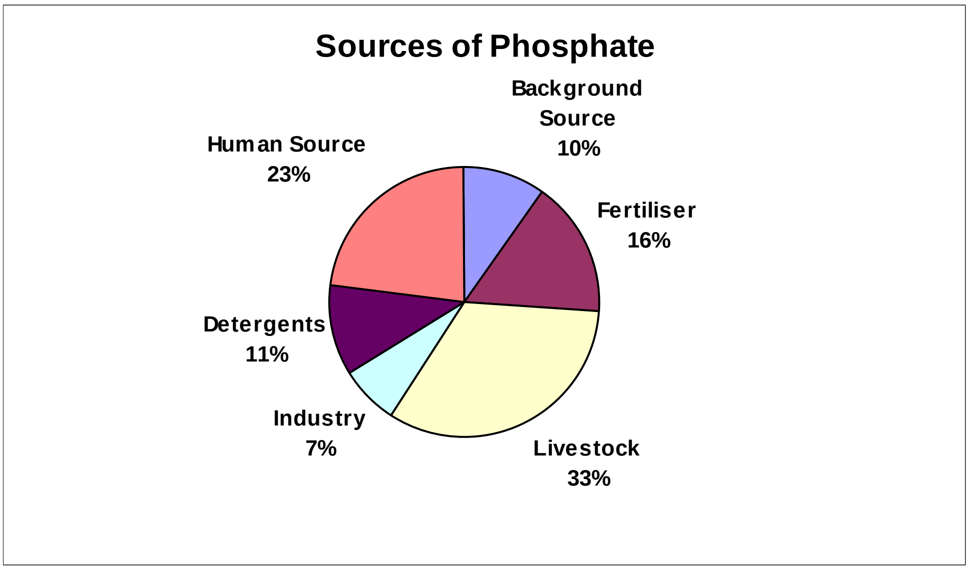

Figure 8: Sources of Phosphate in European Surface Waters

Phosphate source	**Contribution to total phosphorus discharged**
Domestic	81%
Dosing (to reduce lead in drinking water)	12%
Trade effluent	6%
Total	99%

Table 5: Sources of Phosphate and their contribution to wastewater discharges Source: OFWAT 2005

DEFRA [62] reporting the analysis of the Environment Agency's river water quality monitoring data for England and Wales between 1988 and 2001 showed a declining trend in Phosphate as measured at 77% of sites. The sampling sites are designed to assess the impact of point source discharges such as sewage works on river water quality. The decline in phosphate levels were attributed to a combination of improvements in sewage treatment processes and a decline in the use of phosphate based detergents.

Related analyses of UK coastal waters however showed that although direct discharges to coastal waters showed a decline in phosphate levels, discharges from riverine sources had increased over the same time period (1988-2001). Thus although there has been improved control of point source discharges direct to coastal waters including a declining use of phosphate containing detergents, there is still a continuing and increasing source of phosphate from diffuse agricultural pollution.

Sewage treatment operators would prefer that pollutants such as phosphates in detergents are removed at source thus minimising the need for expensive treatment processes. Manufacturers of phosphate containing detergents argue that the phosphate load on the environment from detergents is considerably less than that from agriculture. The Centre Europeen d'Etude des Polyphosphates (CEEP) also make the point that the materials commonly used to replace phosphates in detergents: zeolites create their own environmental burden namely an increase in the amount of sewage sludge produced. [63]. CEEP also report studies on the development of phosphate recovery for recycling.

The complexity of issues such as that surrounding phosphates in detergents serve to emphasise the need for a holistic and objective view rather than one serving vested interests. Techniques such as life cycle analysis have a role to play here: life cycle analyses carried out for phosphate and phosphate free detergents concluded that neither product could be declared better than the other and that both have environmental impacts albeit different ones.[63]

Recommendation (17): Chemical sciences work to ensure sound and objective science is used in defining any legislation and regulations relating to the control of ingredients and formulation of household products. A particular issue is the current European debate on phosphorus.

The sections above have covered straightforward "supply led" scenarios where although the quantity of water used may be significant, there are no quality issues other than health and hygiene and the end use of water is principally domestic in character.

However, the needs of many industrial water users can be much more complex because of the nature of the contamination in the process water potentially available for re-use. Similarly, in "demand led" domestic situations the quality of water available may require greater use of technology. The next section considers situations where quality issues and/or the need to recover valuable raw materials demand far more sophisticated technology than those considered so far.

The role of Green Product Design for domestic products and industrial ancillaries is dealt with more comprehensively in Chapter 8.

Technologies for Water Efficiency and Management

<u>Sedimentation and Filtration</u>

Sedimentation and filtration are the most widely used technology for water purification. The removal of suspended solids (sand, silt and other larger debris) is a prerequisite for further processing to achieve higher water purity. [64]

Purification efficiency is dependant on the concentration and nature of the solids to be removed. Fine, 'sticky' or biological material is more difficult to remove than coarse discrete particles. Chemical additives are often required to achieve an acceptable quality of treated water; this may have implications for the re-use or recycling of the waste generated by the process. The efficiency of sedimentation and filtration is generally very high with over 90% of the raw water being converted to usable product.

The developments in sedimentation and filtration systems have been driven by the demand for higher productivity from restricted space; this may have reached a technological limit. Further developments may be made in chemical coagulants and flocculants to enable higher recovery and improved routes of disposal or re-use, such as composting or soil substitutes.

The use of filtration can be sufficient to enable water to meet an acceptable aesthetic quality for re-use, especially if a low grade requirement such as irrigation is available.

<u>Ion Exchange Processes</u>

Ion exchange processes dominate industrial water purification, from power generation to food and pharmaceuticals. Ion exchange material consists of a reactive chemical group immobilised on a support. The chemical group and support material can be selected to optimise the process depending on the desired result. Only dissolved substances carrying an electric charge (ions) are removed through the process. The reactive group is prepared in a form that will exchange a 'useful' ion for an ionic contaminant, such as sodium for calcium in water softening. Industrial ion exchange operates at around 90-95% efficiency.

Ion exchange media require 'regeneration' to return the exhausted material to the optimal state. This generates produces a waste stream of concentrated regenerant (such as brine, sulphuric acid or sodium hydroxide) which requires disposal.

The more widely used processes employ a polystyrene support material with a sulphonic acid or amine based reactive group.

Ion exchange processes can be designed to remove specific contaminants from waste and marginal water sources to allow recovery and recycling. This is especially valuable in for the recovery of metals such as copper, cadmium and gold. Using ion exchange at a point of contamination before waste is blended or diluted can not only provide water saving but also recovery of valuable raw materials.

<u>Absorption Processes</u>

Absorption processes are widely used to remove colour and odour from both potable and non-potable water supplies. The natural decay of biological material and the presence of bacteria in water produce a wide range of organic compounds that give water colour and odour. Also anthropogenic chemicals such as pesticide residues are often removed with adsorption.

The type of compound removed in the absorption process has a very significant impact on the routes available for disposal or recovery of the absorbant. Activated carbon, prepared from coal or coconut shell is the most widely used material and can be easily regenerated with steam. Other synthetic materials similar to ion exchangers are used for greater specificity.

In the same way as ion exchange, tailored absorbents can be made that allow use at the source of contamination in order to recycle water and recover valuable materials.

Membrane Processes

Membrane processes are growing rapidly in popularity for water purification as advances in efficiency and reduced material costs are realised. Membrane materials and design allow the process to be optimised to suit the application and can offer a robust treatment scheme. Due to the nature of the membrane multiple treatment steps can be carried out in a single process.

The membrane consists of a polymer material (plastic, ceramic or metal) either self supporting or layered onto a support fabric, arranged as sheets or hollow fibres (fine straws), with a controlled porosity. The pore size is determined by both the material and the preparation methods and range from the size of a bacterium to the atomic radius of an ion.

Microfiltration: membranes with a pore size between $10\mu m$ and $0.5\mu m$ (range of an optical microscope) can be used as filters able to remove the finest visible silts down to bacteria and microbial spores, such as Cryptosporidium.

Ultrafiltration: membranes with a pore size between 0.5μm and 0.005μm (5 x 10-9m) down to the size of a virus or a fragment of DNA. These membranes are widely used to both remove colour and sterilise water. Depending on the composition of the raw water both MF and UF can operate at a conversion of 90 to 99%.

Nanofiltration/reverse osmosis: Reverse osmosis (RO) is widely used in water treatment / purification to reduce the dissolved solids content of water, e.g. in desalination of seawater. The process works by the use of a 'semi-permeable' membrane that allows the passage of water by chemical action but blocks the passage of ions. RO can produce very high quality water at a recovery ratio of 70-75% depending on the raw supply. RO blocks all dissolved ions.

Nanofiltration (NF) is a similar process that allows an increased passage of monovalent ions, in effect softening the treated water (selectively removing Ca, Mg but also SO_4). Generally RO and NF require a process stream free from dissolved solids, however certain equipment configurations can tolerate high levels at the expenses of production efficiency and energy cost. The raw water is separated by the process to give a dilute or permeate stream and a concentrate or reject stream. The permeate is the high quality water for recovery. The reject contains all the separated ions providing a possibility for the recovery of valuable raw materials.

Electro-deionisation

Electro-deionisation (EDI) is widely used for the desalination of sea, brackish and process water. An electrical potential is applied across a stream of water encouraging the migration of dissolved ions to the anode or cathode depending on their charge. An ion selective membrane allows the passage of cations or anions into an adjoining chamber, alternating the membranes to produce a series of channels will produce dilute channels (with depleted ion concentration) and concentrate channels (with enriched ion concentration).

Electro-deionisation and electro-dialysis are widely used in the desalination of seawater and for the production of very high purity waters for pharmaceutical and semiconductor industries. The controlled removal of ions is achieved without the requirement for chemical regeneration with ion exchange.

EDI systems are being developed for point of use applications in the same manner as ion exchange technologies, the processes are limited by the solids and organic burden of the waste stream.

Thermal Processes

Distillation is very widely used for the desalination of seawater for potable use and also for the preparation of purified grades of water for pharmaceutical applications.

Where waste heat is available then thermal purification / separation processes may be a viable choice. Advances in the design of thermal equipment, using multiple stages and reduced pressures have increased the overall thermal efficiency dramatically.

Distillation is also suitable for recycling water from difficult waste streams. Some low boiling point compounds may be carried over in the vapour phase, but ionic and biological contaminants will be retained in the waste stream.

Future Trends

The chemical science drivers are to develop materials that can reduce the energy cost per megalitre. Microfiltration operates at 0.1~1bar and reverse osmosis at 5~80bar. Materials with intrinsic antifouling properties and high permeation rates are required, possibly based on nano-particle modification of polymer materials.

It is feasible that a local recycling scheme can be developed where domestic grey and black water are contained in a digester comprising a microfiltration system to recycle water for grey uses and a hydrogen, methane or bio-diesel forming micro-organism colony to provide ‘green’ fuel and sludge extraction for composting. [65]

Recommendation (18): The RSC should stimulate the research and development of materials for microfiltration of waters that can reduce energy costs per megalitre of treated water.

Process Integration and Management Techniques

As well as the approaches discussed in the sections above, there are several management system techniques that can contribute towards the efficient use of water.

PINCH techniques were first developed for the efficient use of energy [66] and forms part of an engineering design technique known as process integration. Process integration techniques were further developed [67, 68] to cover waste water minimisation and the design of effluent treatment systems.

PINCH treats a water-using process as an exercise in mass transfer from a process stream that is rich in contaminants to one that can be regarded as a water stream. Contaminants can be any component such as COD, metals, suspended solids etc that limit the re-use of the water in another process if the concentration of that contaminant is above a certain critical level. This critical level is termed the *water-pinch point.*

The key point for the chemical sciences in the use of PINCH is that it is essential that users have a good understanding of the process chemistry involved so that the water-pinch points are correctly defined. This encompasses the need to measure waste stream contaminants systematically and interpret them appropriately in relation to the water quality needs of other processes. It also results in an on-going need for water quality measurement and related process control.

An integrated approach to water management on a site might involve a water PINCH study from which a range of water efficiency projects might be identified. These might range from simple maintenance tasks involving little more than plumbing alterations, through rain water and grey water systems discussed above and finally to more capital intensive technology. The key point however is that the approach is driven by the definition of the quality of water required in a particular process.

The concept that waste water streams are a resource rather than a waste to be disposed of is an integral part of the PINCH approach to the efficient management of water resources. This approach is also known as "zero discharge" [69]. Chapter 3 of this report covers treatment processes and chemistry for waste water.

Similarly, the implications of the great range of chemicals that are finally discharged to sewer or watercourse for the requirements of the Water Framework Directive are considered in chapter VV of this report.

The Process Industries Skills Dialogue 2002 [70] covers a wider selection of process industries and identified the need for improving skills so that businesses can carry out continuous process improvements. This includes the content of science and engineering courses at colleges and universities. This is another vital area where the chemical sciences can provide relevant content and delivery, particularly from those with practical experience.

Similar concerns have been noted in the chemical industry. In their recent report on the skills gaps in the chemical industry, Cogent [71] particularly identified a "lack of skills and knowledge required in order to make progress on process and productivity improvements".

Recommendation (19): Chemical sciences pursue avenues for contributing to improving skills in the chemical science aspects of continuous process improvement at all levels: process operators to post graduate specialist courses.

Another management approach that can influence the efficient use of water is the adoption of an environmental management system such as ISO 14001: 2004, EMAS or an in-house system. The adoption of any management system does not in itself result in the more efficient use of water. However, the organisation has a better chance of managing water more efficiently and effectively by choosing to commit to the active measurement and management of water as part of such a system,

Conclusions

- Both the potable water distribution network and sewerage system can be regarded as long and complex linear chemical reactors. As with any chemical reactor, altering the inflows, outflows, pressures and temperatures can have a profound effect on the reactions taking place in the system.
    - In the case of potable water in the distribution network, current initiatives aimed at reducing both leakage and potable water demand will have a significant impact on the chemistry as flows within the network change.
    - The predicted changes in sewer flows resulting from changes in urban precipitation (climate change) will undoubtedly have an effect on sewer chemistry; however little detail is known at this stage about these changes and the full extent of their impact on the chemistry and management of downstream operations.
    - It is also expected that there will be complex interactions resulting form the combination of changes in water use and concentrations of micropollutants in sewage.
- Economics of the current cost of water in the UK mean that rain water and/or grey water recycling systems do not have proven cost benefit for individual households. This scenario may change if security of supply issues (especially in South and East of England) are factored in.
- Membrane barrier processing techniques based on reverse osmosis or ultrafiltration will dominate local recycling schemes for greywater (ignoring rainwater storage and use). This is due to the multiple purification steps achieved by a single membrane process step.
- In the UK, the current technologies for the use of rain water and reuse of greywater have been installed by “early adopter” enthusiasts motivated by environmental and/or social concerns. Further uptake requires recognition

of this situation and the adoption of appropriate policies and programmes in order to move the technologies into more mainstream use.

- Uptake of such systems would be assisted by the development of more robust "fit and forget" dosing and control technologies and by the introduction of appropriate quality standards for sub potable water.
- Positive interaction between water efficient appliances and approaches and user/consumer is vital if they are to be effective.
- There is a requirement to use techniques such as life cycle analyses where there is a need for objective scientific analyses for complex issues such as environmental impacts of household products and extra energy costs, contaminants and resource costs associated with rain and grey water use.

Summary Recommendations for Chemical Science Priorities

Recommendation (1): Chemical scientists should continue to be involved in the consultations and drafting of appropriate legislation and regulation so that sound science is incorporated into legislation, regulation and codes of practice.

In particular, there is a need for RSC to contribute to the debate as to what in terms of the Water Framework Directive, constitutes "good ecological status" and how this may be measured.

Similarly, specific measures for the control of Priority Hazardous Substances have significant implications for UK Industry and there is an urgent need to identify the 'chemistry and interaction of these substances' in surface waters, sewage and groundwaters and their potential impact.

Recommendation (2): The RSC promote innovative research into appropriate sensor technologies to enable inexpensive flow and pressure measurement.

Recommendation (3): RSC to promote collaboration between water engineers and scientists and materials and sensor engineers and scientists, with a view to specifying and promoting combined sensor and materials research and development, and transferring the technologies into the water industry.

Recommendation (4): RSC comment on Ofwat's consultation on periodic review periods in the context of the ability to make the necessary scientific and technological changes within the current review periods.

Recommendation (5): The RSC should promote the development of new disinfection processes and chemicals; not only for bacteriological water quality reasons, but also for wider public health benefits of disinfection without harmful by-products. Bactericidal materials research should be promoted to further develop or transfer the technology into the water industry sector.

Recommendation (6): Water engineers and scientists collaborate with materials scientists in order to specify and develop optimal materials for leakage prevention and water quality maintenance.

Recommendation (7): RSC reviews the instruments, sensors and analytical approaches and techniques that may be best applied to meet the needs of WFD.

Recommendation (8): RSC attempts to address changes in the chemistry of deposits on the catchment surface due to climate change and to assess their propensity to mobilise due to changes in the impact of urban storms.

Recommendation (9): There is a need to understand the changes in the chemistry of the sewer flows due to increased precipitation intensity and to assess the impact of these potential changes on the efficiency of the WwTW to meet future WFD requirements.

Recommendation (10): RSC examines the chemistry of flood flows and assesses the potential impact of WFD substance consents on health at the time of flood events.

Recommendation (11): RSC to learn the constituents of dilute sewage and to suggest appropriate low- cost, low-energy treatment systems or alternative sewage strengthening technologies, as contingency.

Recommendation (12): RSC completes an extensive review of knowledge associated with the implementation of sustainable remediation measures from a chemistry viewpoint with a view to identifying shortfalls of knowledge and the potential for efficiencies and savings.

Recommendation (13): RSC stimulates research to quantify the effect of the changes in operational and management strategies of sewerage assets and their potential impact on asset condition.

Recommendation (14): RSC stimulates a programme of research to identify more clearly the interactions, fluxes and pressures associated with integrated water management from a 'chemistry' perspective.

Recommendation (15): Chemical sciences pursue the introduction of a universal statutory standard for sub-potable water.

Recommendation (16): Chemical sciences investigate in detail overseas experience of "fit and forget" formulations and dosing systems for disinfection of rain water and grey water and their appropriateness for use in the UK.

Recommendation (17): Chemical sciences work to ensure sound and objective science is used in defining any legislation and regulations relating to the control of ingredients and formulation of household products. A particular issue is the current European debate on phosphorus.

Recommendation (18): The RSC should stimulate the research and development of materials for microfiltration of waters that can reduce energy costs per megalitre of treated water.

Recommendation (19): Chemical sciences pursue avenues for contributing to improving skills in the chemical science aspects of continuous process improvement at all levels: process operators to post graduate specialist courses.

Appendix 1 Scotland: top non domestic water users demand ('000m^3/year) 2004

Sector	**Direct Abstraction**	**Public water supply**	**Total**
Food Processing	2,622	9,644	12,266
Maltsters	1,566	1,584	3,150
Micro brewers	46	318	364
Mineral water	859	121	980
Distillers (malt)	76,490	n/a	n/a
Chemicals	5,491	23,748	29,239
Electronics	0	9,450	9,450
Metals	3,980	1,970	5,950
Textiles	448	509	957
Paper	69,281	13,386	82,667
Fish Farming	1,617,350	0	1,617,350
Agricultural Irrigation	8,265	0	8,265
Scottish Water	926,000	0	926,000

Ref SNIFFER report

n/a=not available

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Although its prime aims are environmental, the Directive embraces all three principles of sustainable development. Environmental, economic and social needs must all be taken into account when *river basin management plans* are being developed (Article 9).

Measures to conserve water quantity are introduced as an essential component of environmental protection. Unless minimal, all abstractions must be authorised and, for groundwater, a balance struck between abstraction and the recharge of aquifers (Article 11).

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