WATER, MEGACITIES
AND GLOBAL CHANGE

LONDON

Water in London and the Response to Climate Change

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Part A: General Context

CHAPTER 1
Description of London's Geography and Development

Introduction

London is the largest urban area and capital city of the United Kingdom, located in South-east Great Britain. The London region covers an area of around 1600 square kilometres (610 sq mi), and the population recently reached its highest level ever of 8.6 million with a projected population of 11 million by 2050 [i]. It is surrounded by a densely populated area which is sometimes referred to as 'Greater London' with a population approaching 13 million.

London is one of the world's leading financial centres and much of its economy is based on service industries, the move away from manufacturing taking place earlier then for many cities, generally after the Second World War. According to Wikipedia its success as a service industry centre can be put down to a number of reasons:

- English being the native language and the dominant international language of business;
- its position as the capital of the former British Empire;[11][12]
- its location within the European Union, since the EU has a population and GDP larger than the US;[13]
- the special relationship between the United Kingdom and United States,[14] and the United Kingdom's close relationships with many countries in Asia, Africa and the Middle East, particularly those in the Commonwealth of Nations;[15][16]
- its location in a central time zone that allows it to act as a bridge between US and Asian markets;[17]
- English contract law being the most important and most used contract law in international business;[18]
- relatively low taxes for corporations and non-domiciled foreign individuals;[19][20]
- a business friendly environment (e.g. in the City of London the local government is not elected by the resident population but instead by resident businesses – the City of London is a business democracy);[21]
- good transport infrastructure particularly its aviation industry;
- a high quality of life for the average resident

It is also a major tourist destination and Mastercard cited it as the most visited city in The world as a tourist destination[ii]

London's Rivers

London is a port on the Thames, a navigable river, which flows from west to east and rises in Chalk hills. The river has had a major influence on the development of the city, which was located at the lowest point at which the river could be bridged. For some time London Bridge was the only bridge in the city with the first bridge being built by the Romans. London began on the Thames' north bank and for a long time this remained the focus of the city. When more bridges were built in the 18th century, the city expanded in all directions as the mostly flat or gently rolling countryside presented no obstacle to growth.

The river is tidal throughout London up to the point of Teddington Weir which was built in 1810. Within the area of the city it is fed by a number of tributaries, the Ravensbourne, the Darent and its tributary the Cray, the Mole and the Wandle to the south and the Colne, Crane, Brent, Lea, Roding and Ingrebourne to the north. A major canal, The Gran Union Canal, original known as the Grand Junction Canal also links the city with the Midlands. This was built in 1805[iii]

Topography

London lies within a bowl with most of the built-up area lying on the Tertiary and younger sediments, and a small part of south London (Sutton, Banstead and Croydon) lying on the chalk back slope of the North Downs. The centre of the basin is dominated by the modern valley of the Thames, which forms a level corridor running from west to east. The modern floodplain is around half a mile wide to the west of Greater London, expanding to two miles wide to the east. This is bordered by slightly higher and older terraces often extending several miles from the floodplain, for example in Hounslow and Southwark.

There are a few notable hills in Greater London, but none of them more than a few hundred feet high, and they have not impeded the development of the city in all directions. It is therefore very roughly circular. The hills in the City of London, from west to east, Ludgate Hill, Corn Hill and Tower Hill, are presumed to have influenced the precise siting of the early city, but they are very minor, and most of central London is almost flat. These hills are developed in various gravel terrace deposits of the river Thames.

To the north of the City a ridge capped by sands of the Bagshot formation forms high ground (in places around 130m) including Hampstead Heath and Highgate Hill. This ridge is a surviving area of Tertiary rocks younger than the London Clay, surrounded by former routes of the Thames where much younger deposits overlie the clay. Smaller outliers of younger Tertiary high ground exist to the west of the main ridge such as at Harrow Hill

To the north of this ridge, between the modern valleys of the rivers Lea and Brent, lies a second ridge (a little under 100m), formed of much younger Pleistocene deposits and capped in some locations by glacial till marking the southern limit of glaciation. Further north, ridges of Claygate Beds overlain by the pre-glacial Stanmore gravel form hills and ridges including Mill Hill, Totteridge, Arkley and Monken Hadley, Elstree, and Stanmore and Harrow Weald Commons.

Much of east and northeast London lies on the modern floodplain of the Thames or older terraces, a notable interruption being the remains of the artificial Beckton Alps, an artificial area of high ground created from the spoil heaps of the gas works located there in the late 19th and early 20th century.

Faulting and folding brings the chalk close to the surface just south of the Thames in Lewisham and Greenwich. In south-west London the lower terraces of the Thames stop abruptly at a notable bluff cut into the London Clay and running south from Richmond Hill[iv].

Climate

The climate of London is broadly similar to the rest of the UK, with cool summers, mild winters, no wet or dry season, and often moderate to strong winds. It is classed as a temperate maritime climate according to the Köppen climate classification system. In terms of the local climate profile, the temperature tends to increase towards the centre of the urban area, primarily because of the urban heat island effect, but also because London's topography results in the central area being the lowest part of the region sheltered by the surrounding hills described above.

The tables below illustrate the difference in climate across the basin with Hampstead being on the northern hills, whilst Kew is on the River Thames to the west of the city.

Generally, rainfall in London is less than that on the west of the British Isles as the prevailing south westerly winds carrying rain have often deposited much of the precipitation on the hills to the west of London such as the Cotswolds and the hills further west such as the Mendips as well as and Dartmoor. Whilst this average annual rainfall of between 600 and 750 mm may seem a substantial amount, when considered for a population of over 8 million, water resources in London have to be used carefully, even without taking climate change into account.

London's Development

As mentioned above London was first developed by the Romans and for much of its history has played an important part internationally in addition to its role as the capital city. The original city 'the Square Mile' was contained within walls and the city only expanded outside these to any extent in the 17th century. This expansion was interrupted by the Great Fire of London in 1666 which destroyed around 60% of the city. Although plans to rebuild a completely new city were developed these largely came to nothing and so the street lay out in the 'City of London, which still comes under a separate local authority, is based on the original mediaeval layout.

Climate data for Hampstead 137m asl 1981-2010, extremes 1960-

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	15.7 (60.3)	18.3 (64.9)	23.1 (73.6)	26.6 (79.9)	29.8 (85.6)	33.7 (92.7)	34.4 (93.9)	37.4 (99.3)	29.4 (84.9)	28.3 (82.9)	17.9 (64.2)	15.3 (59.5)	37.4 (99.3)
Average high °C (°F)	7.1 (44.8)	7.4 (45.3)	10.5 (50.9)	13.3 (55.9)	16.8 (62.2)	19.9 (67.8)	22.4 (72.3)	22.0 (71.6)	18.8 (65.8)	14.6 (58.3)	10.3 (50.5)	7.4 (45.3)	14.3 (57.7)
Average low °C (°F)	2.0 (35.6)	1.7 (35.1)	3.5 (38.3)	5.0 (41)	8.0 (46.4)	10.9 (51.6)	13.2 (55.8)	13.1 (55.6)	11.0 (51.8)	8.1 (46.6)	4.8 (40.6)	2.5 (36.5)	7.0 (44.6)
Record low °C (°F)	−10.8 (12.6)	−12.2 (10)	−6.9 (19.6)	−3.2 (26.2)	−0.6 (30.9)	1.8 (35.2)	5.6 (42.1)	4.7 (40.5)	2.4 (36.3)	−2.4 (27.7)	−5.8 (21.6)	−8.4 (16.9)	−12.2 (10)
Average precipitation mm (inches)	64.7 (2.547)	46.6 (1.835)	48.9 (1.925)	51.5 (2.028)	58.0 (2.283)	54.2 (2.134)	50.4 (1.984)	64.4 (2.535)	56.9 (2.24)	77.7 (3.059)	68.3 (2.689)	62.9 (2.476)	704.5 (27.735)
Mean monthly sunshine hours	57.5	76.4	107.1	151.6	192.2	191.0	199.9	193.0	140.8	109.9	69.4	51.6	1,540.4

Source: Royal Netherlands Meteorological Institute[26]

Climate data for Kew, 5m asl, 1981-2010, extremes 1901-

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	16.1 (61)	18.5 (65.3)	22.0 (71.6)	26.7 (80.1)	30.6 (87.1)	34.2 (93.6)	35.0 (95)	38.1 (100.6)	33.3 (91.9)	27.8 (82)	18.9 (66)	15.7 (60.3)	38.1 (100.6)
Average high °C (°F)	8.2 (46.8)	8.7 (47.7)	11.6 (52.9)	14.4 (57.9)	18.0 (64.4)	21.0 (69.8)	23.5 (74.3)	23.2 (73.8)	20.0 (68)	15.8 (60.4)	11.3 (52.3)	8.5 (47.3)	15.4 (59.7)
Average low °C (°F)	1.8 (35.2)	1.7 (35.1)	3.4 (38.1)	4.7 (40.5)	7.9 (46.2)	10.8 (51.4)	13.0 (55.4)	12.7 (54.9)	10.3 (50.5)	7.4 (45.3)	4.1 (39.4)	2.1 (35.8)	6.7 (44.1)
Record low °C (°F)	−12.8 (9)	−11.7 (10.9)	−8.3 (17.1)	−2.1 (28.2)	−3.1 (26.4)	−0.6 (30.9)	3.9 (39)	2.1 (35.8)	1.4 (34.5)	−3.9 (25)	−7.1 (19.2)	−11.7 (10.9)	−12.8 (9)
Average precipitation mm (inches)	57.2 (2.252)	41.9 (1.65)	42.8 (1.685)	45.3 (1.783)	48.8 (1.921)	49.3 (1.941)	46.8 (1.843)	51.2 (2.016)	52.2 (2.055)	69.7 (2.744)	60.6 (2.386)	56.6 (2.228)	622.5 (24.508)
Mean monthly sunshine hours	59.8	79.9	118.2	173.3	205.3	203.6	218.4	211.1	146.4	117.2	70.6	49.6	1,653.4

Source: Met Office[25]

In the 18th and 19th centuries London continued to grow and in the 19th century was the largest city in the world. This in turn brought problems of public health and two engineers had a major impact on the water supply sanitation then and up to the modern day. Up until the 17th century London had been supplied by water through a number of springs, wells and conduits as well as the River Thames and its tributaries with water bearers selling the water to those located further away from these sources.

The Development of water supplies

However, as the population of London grew the existing water supplied were insufficient and Sir Hugh Myddleton was responsible for developing 'The New River' which was a canal which brought water in from Hertfordshire to north east London at Clerkenwell. The supply was managed by 'The New River Company. This was followed by a number of other private water companies which developed their own water resources and distribution systems. In the 1852 the Metropolis Water Act required all water companies to provide wholesome water and all water had to be filtered. These water companies were eventually to be the foundation of the Metropolitan Water Board which was founded at the start of the 20th century[v].

Water sources and treatment continued to be developed in the 19th century and early 20th century with water abstracted above Teddington Lock being treated at various treatment plants in West London using slow sand filtration. This method of treatment was also used for a new water resource for north east London developed in Walthamstow at Coppermills. Networks of iron pipes were used to deliver the drinking water to properties or to communal hand pumps and storage cisterns. Storage for raw water using pumping into raised earth walled reservoirs was developed in the 20th century along the Lea Valley and in the west of London with the most recent reservoir being the Queen Mother Reservoir opened in 1976.

London's water resources and infrastructure in the 21st century

London still derives the majority of its water supply from the River Thames and its tributaries with around 70% coming from rivers, although the rest of the water comes from boreholes into the underlying chalk. Much of this system is based on that installed in the 19th century and although the mechanical plant and system of powering has been updated, much of the civil engineering works are the originals built in the 18th and 19th centuries. However, a number of more recent developments are covered in Chapter 4 which explains how the capital will continue to be supplied into the future.

The development of sewage collection and disposal

Sewage disposal was rather slower to develop. Generally, waste water was collected through channels which ran in the centre of streets and thence to the local water course which in turn flowed into the River Thames. Until the 18th century the River Thames was relatively clean and supported a thriving fishing industry. Some of these water courses were built over and thus became permanent sewers. As the population grew the river Thames became more and more polluted until by the early 19th century it was little more than an open sewer. In 1858 this became particularly bad such that disinfected sheets had to be hung over the windows of the Houses of Parliament and cartoons appeared in the National Newspapers. Parliament realised the urgency of the problem and resolved to create a modern sewerage system.

Joseph Bazalgette, a civil engineer and Chief Engineer of the Metropolitan Board of Works, was given responsibility for the work. He designed an extensive underground sewerage system that diverted waste to the Thames Estuary, downstream of the main centre of population. Six main interceptor sewers, totalling almost 100 miles (160 km) in length, were constructed, some incorporating stretches of the built over rivers mentioned above. Three of these sewers were north of the river, the southernmost, low-level one being incorporated in the Thames Embankment.

The intercepting sewers, constructed between 1859 and 1865, were fed by 450 miles (720 km) of main sewers that, in turn, conveyed the contents of some 13,000 miles (21,000 km) of smaller local sewers. Gravity allows the sewage to flow eastwards, but in places such as Chelsea, Deptford and Abbey Mills, pumping stations were built to raise the water and provide sufficient flow. Sewers north of the Thames feed into the Northern Outfall Sewer, which feeds into a major treatment works at Beckton. South of the river, the Southern Outfall Sewer extends to a similar facility at Crossness.

During the 20th century, major improvements were made to the sewerage system and to the sewage treatment provision to substantially reduce pollution of the Thames Estuary and the North Sea. The waste water system was maintained as a combined storm and sewage collecting system, which in itself can cause problems.

Much of this 19th century and early 20th century is still in use such that London has some of the oldest water and waste water infrastructure in the world. More than half of Thames Water's water mains are over 100 years old; around a third are over 150 years old[vi]

Substantial bombing in the Second World War has meant that although records were maintained of the original pipe networks, the areas where rapid repairs were carried out, often by poorly qualified people are less well recorded so that the exact route of many pipes cannot be confirmed.

The Future

The Nesta web site[vii] identifies some of the future trends for Londoners as being:

1) Londoners relating more to their local community or worldwide than London as a city
2) More collaborative consumption such as the 'Boris Bikes' and car shares.
3) An active ageing population, although still younger than the average age in the rest of the UK.
4) Flexible working
5) A fragile energy supply and environment leading to innovative responses
6) More inequality including unequal access to communications and information
7) Increasing collection and use of personal data

This is echoed by a report from the Young Foundation[viii] which also suggests that diversity in religion, culture and ethnicity will grow and as well as the trend away from marriage and towards women having children at a later age. This report also comments that although currently working hours in London are amongst the longest in Europe, this may change in the future, with increased leisure time becoming widespread. Whilst it is likely there will be a move in the global economy towards countries outside Europe, the Major of London has a strategy which sees London staying as the world capital for business, the most competitive city and the top tourist city in the world[ix]. All this means continued growth in demand for water and sewerage services as well as pressure on the River Thames and other open water for recreational and even for transportation purposes.

Table 2: Attractiveness of London to business

	2006	2007	2008	2009	2009 Leader
Availability of qualified staff	1	1	1	1	London
Easy access to markets	1	1	1	1	London
Quality of telecommunications	1	1	1	1	London
External transport links	1	1	1	1	London
Cost of staff	16	25	29	28	Bucharest
Climate for doing business	5	2	5	4	Leeds/Birmingham
Language spoken	1	1	1	1	London
Office space - value for money	29	18	24	23	Berlin
Internal transport	1	1	1	1	London
Availability of office space	1	2	5	2	Berlin
Quality of life	7	11	14	11	Barcelona
Freedom from pollution	26	29	27	29	Geneva

Figures indicate London's ranking amongst European cities each year, as rated by business. Factors are ranked by importance to businesses.
Source: European Cities Monitor, Cushman and Wakefield 2009

Transportation is a major issue in London and construction of some major rail links, cross rail currently and HS2 in the future may affect London. In addition, although already one of the most heavily traffic Cities for air traffic, it is projected that this will continue to grow and the location of new facilities is still debated. The mayor of London is keen for the city to become a 'greener city' and this will affect a wide variety of activities including transport. He is keen to promote cycling as well as public transport. With so much of the water and waste water infrastructure lying under the road, the future use of roads and levels of traffic are of importance in the management of the utility networks beneath them.

Another issue for London is its ageing infrastructure. Apart from its water and sewerage system, it has the oldest underground railway and much of its housing and office building stock is over 100 years old. The management of these properties needs to be managed sympathetically as even outside the main tourist centres it adds to the character of London.

CHAPTER 2
The governance and structure of the water industry in London

When considering the management of the water cycle in London it is necessary to consider the structure for the whole of the UK to understand London's place within this structure. In particular, it is often mistakenly quoted that the water industry in Great Britain is privately run. This is not true. Scotland, Northern Ireland and the outlying islands such as the Isle of Mann and the Channel Islands have their own systems and all have publically owned water utilities, although the exact governance varies for the different countries. The water governance for London comes within the structure for England and Wales which is described below.

Much of the structure of the water industry in England is based on that proposed under a major restructuring implemented in 1974. Prior to this time water supply, sewage collection and disposal and river management was undertaken by a variety of joint boards, municipal authorities and private water companies as well as 29 river authorities. Under the 1973 Water Act transferred the functions of all these organisations except the private water companies to ten multi functional 'water authorities' based on river basin catchment areas. Therefore, Thames Water Authority took on the management of the River Thames and its tributaries as well as the provision of water and the collection and treatment of waste water across the whole of the Thames catchment apart from where water companies such as the Lee Valley Water Company and the Sutton Water Company were in existence, when the water supply continued to be provided by them.

The new water authorities identified that a huge amount of investment was needed to bring facilities up to standard and this expenditure requirement was further increased by new European Directives stipulating the quality of bathing waters and new quality standards for drinking water. It was therefore decided to privatise the water authorities, establishing them as publically limited companies (plcs). The river management activities were transferred to a new national organisation, The National Rivers Authority (NRA).

To ensure that strict financial controls were exercised a new role of the 'Director General of Water Services' was identified responsible to government via the Department for the Environment. This role also monitored the level of service provided by the both the newly privatised and the existing water companies. The role of Ofwat has largely remained unchanged, although on 1 April 2006, the Director General was replaced by the Water Services Regulation Authority. The name "Office of Water Services" is no longer used, as it had no legal basis, although the Authority is still referred to as 'Ofwat'. The Authority is headed by a chairman, currently Johnson Cox, and a Chief executive, currently Catherine Ross.

The existing water companies currently operating under their own legislation would be brought under the same financial and regulatory regime, although they could choose whether to become 'plcs'[x]. Both water and sewerage companies and water only companies had to refer any mergers to the Monopoly and Mergers Commission or its subsequent body, the Competition Commission. Since 1989 there have been a number of mergers so that water is supplied by four companies, Thames Water, Affinity Water, Sutton and East Surrey Water and Essex and Suffolk Water (part of Northumbrian Water). Sewage collection and treatment is entirely provided by Thames Water.

The Water Act of 1989 established the new structure which was later simplified by four further acts passed in 1991. The Water Industry Act set up the new plcs and defined the role for the Director General of Water Services. The Statutory Water Companies Act covered the water only companies. The Water Resources Act set out the functions of the new National Rivers Authority and the Land Drainage Act which transferred the functions of various drainage organisations to the NRA.

In addition, some further provisions covered other regulatory issues. The Department of the Environment (Now called the Department for Environment, Fisheries and Rural Affairs or DEFRA) Secretary of State could issue Water Quality Regulations which set the quality standards required for drinking water. These regulations exist and have been updated from time to time. There are also regulations which control the standards for water installations inside private properties which the water companies are also responsible for administering. All the regulations are policed by the Drinking Water Inspectorate (DWI) which was set up under the Secretary of State to monitor and report on the water quality achieved by the water service companies. Under the legislation the DWI has the right to prosecute for failure of a water service company to provide drinking water of a suitable quality. Similarly, the NRA has the right to prosecute any company providing sewerage services for discharging effluent which failed to meet the required standards. They also monitored the amount of water abstracted from the environment, whether it be from rivers or below ground sources and had the power to prosecute in the event of over abstraction.

The role NRA was later expanded with the formation of the Environment Agency (EA) in 1995 to achieve a more co-ordinated approach. This new organisation, still in existence, includes responsibility for[xi]:

- preventing flooding and pollution incidents;
- reducing industry's impacts on the environment;
- ensuring waste produced is correctly disposed of;
- advising on land use planning, including advice on regional planning, development plans and planning applications;
- cleaning up rivers, coastal waters and managing water resources
- improvement of contaminated land;
- improving wildlife habitats;
- improving and enhancing inland waterways and ensuring sustainable inland fisheries.

As mentioned above, water charges were controlled by the Director General for Water Services, who set charges over a five-year period based on the rate of inflation plus or minus a constant factor. The charges are set following the submission by each water company of a detailed business plan covering the next five years along with an asset management plan. These have to take into account a detailed water resources plan which is also approved by the EA and which must take all aspects of balancing supply and demand into account – both efforts to reduce demand as well as initiatives to increase the availability of supplies.

Water charges were originally largely levied on the basis on 'rateable value', i.e. the value of the property. However, gradually water metering has expanded and all commercial properties are charged on the basis of a water meter. However, less than a quarter of London's domestic customer's are currently charged on the basis of a water meter[xii]. Installing water meters is complicated in London by the age of the housing stock, much of which is greater than 100 years old. In the past the attitude of domestic customers was also a problem as they felt that the UK is a 'wet' country and that access to clean water is a right which should not be limited by the ability to pay. However, this attitude is changing, in spite of newspaper articles claiming that water meters will increase the cost a family has to pay and MPs claiming that poorer families will have to send their children to school without washing.xiii A recent survey by Ofwatxiv showed that participants thought metering was the fairest form of charging, but had no interest in 'green tariffs'.

More than two thirds of Londoners pay a flat rate for their water based on the rateable value of their home with around a third already on a meter. The average Thames Water bill is £354, the second lowest in England and Wales.

In addition to the regulator the Consumer Council for Water (CCWater) was set up as a watchdog for the water industry and to represent customers. Its primary functions are to provide advice and represent consumers on water matters and sewerage and to investigate and handle complaints made against licensed water suppliers or companies in England and Wales. It is a non-departmental public body accountable to Parliament and the National Assembly for Wales[xv]. A number of Memoranda of Understanding have been drawn up between CCWater and other organisations to define how CCWater will interact.

Originally the water companies' customer service performance was generally based on performance indicators such as the speed of handling complaints and the level of operational service based on e.g. the number of breaks in supply lasting for more than 3 hours. These measures were compiled into a Operational Performance Assessment (OPA) which was used to rank the performance of water companies and had an impact on the returns which a water company was allowed to make on capital investment in the following five year price review. The difference in returns could be as much as 1.5% between the best and worst performing water companies so water companies worked hard to try and achieve high performance.

As water companies improved their service, differentiating between them to rank them became more difficult and in 2013 Ofwat introduced the Service Incentive Mechanism (SIM). This was designed to continue to improve the level of service that water companies provided. It is based on two consumer experience measures.

- A **quantitative measure** based on the number of complaints and unwanted contacts a company receives.
- A **qualitative measure** (one based on the quality of the experience) derived from a consumer experience survey.

These two measures aim to capture both the number of times a company fails to meet the expectations of its consumers, as well as the experience of those consumers and encourages companies to understand and take responsibility for delivering what their customers expect. Again the performance under SIM affects the returns a water company can make.

As part of the process of improving the water companies' customer service, and making customers central to the business planning process, Customer Challenge Groups were established at the start of the 2014 Price Review (PR14) for each water company to scrutinise and challenge the customer input and engagement by companies as part of the business planning process. Companies now conduct extensive research through surveys and focus groups to understand their customer needs, priorities and opinions.

The move to take customer preferences into account is culminating in the move for retail competition which was introduced under the Water Act of 2014. Plans for this move are being developed through Ofwat's 'Open Water Programme'.

Throughout this discussion no mention has been made of the role of local authorities in the provision of water services. In much of the rest of England this role is limited to the management of surface water run-off not coming under the jurisdiction of the EA, such as minor water courses and road run off. However, the Greater London Authority Act 2007 supplemented and updated the GLA Act 1999 and granted some additional powers to the Mayor of London and the London Assembly, such that within the capital the Major of London responsibility to promote economic development and wealth creation, social development, and the improvement of the environment.

The Mayor has a range of specific powers and duties, and a general power to do anything that will promote economic and social development, and environmental improvement, in London. Before using many of his powers the Mayor must consult with Londoners, and in all cases, the Mayor must promote equality of opportunity[xvi].

The Mayor sets out plans and policies for London covering transport, planning and development, housing, economic development and regeneration, culture, health inequalities, and a range of environmental issues including climate change, biodiversity, ambient noise, waste disposal and air quality. These individual plans fit together to help deliver the Mayor's policies. Between them, these plans must also contribute to sustainable development and the health of Londoners. These policy documents include a range of documents covering water supply and waste water disposal policy as well as the management of flood water. The documents recognise the role of the water companies in providing water services as well as the role of the EA in managing the water environment. However, they also consider other stakeholders and provide an overall framework to the water environment which does not exist in other parts of the country.

Part B: Challenges and Solutions

CHAPTER 3
Priority Issues Related to Climate Change

Introduction

A report by the London Climate Change Partnership[xvii] identified the impact of climate change on London as affecting: energy use, flooding, water resources, health, biodiversity, the built environment, transport, business and finance, tourism and lifestyle. There can be no doubt that the impact on London will be wide ranging and the impact on all aspects of the water environment will be substantial.

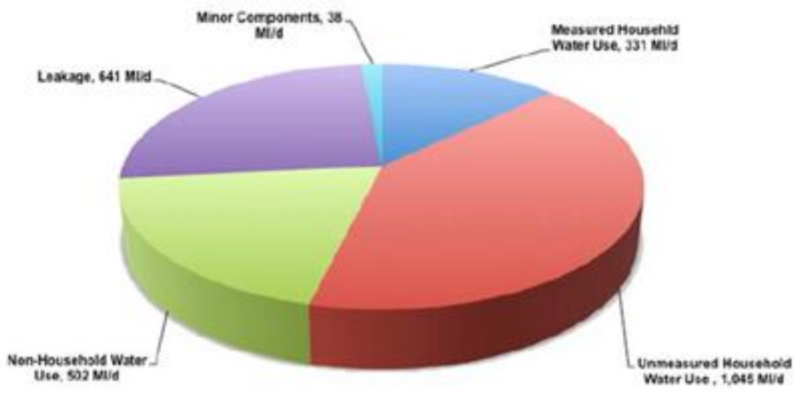
Increased Water Demand

Over the last 30 years, London has experienced extreme high temperatures that have affected the health, comfort of Londoners and the economic vitality of the city. These include the heat waves of 1976, 2003 and 2006 and the unseasonal hot weather of April, September and October 2011. Due to the exacerbating factors of London's existing Urban Heat Island and climate change projections for increased average temperatures and more extreme hot weather events in the South East of England, the impact of rising temperatures in summer is more extreme in Central London.

This in turn means that the impact on water demand is more extreme with per capita demand in the hot summer months rising to levels hitherto for unseen. The current levels of water use are shown below.

As shown in the diagram below by far the largest amount of water is used by the currently unmetered domestic properties. Although in London garden watering tends to be less of an issue than in some other UK cities, due to the high value of land and the ensuing smaller size of property, it is still a factor and the current lack of any financial incentive to reduce garden watering along with the British love of gardening means that this is still a major issue.

Figure 0-2: Demand as reported in 2011/12



Source: Thames Water Final Water resources Plan 2015 - 2014

Londoners use more water than the national average (167 litres per person per day in 2009-10 compared to 146 litres per person per day), largely because they live in small households, which are less water efficient. Apart from climate change, the move towards more small households and the ageing population mentioned earlier will also exacerbate the trend in increasing demand along with the overall increase in population predicted for London and discussed earlier.

Water lost due to leakage from the distribution network has also been an issue in the past, particularly for Thames Water with the water company coming under scrutiny and criticism in the early 21st century. This culminated in the close examination of Thames Water's performance in managing its network assets and levels of leakage at the public enquiry over planning permission to build a desalination plant in 2006. The other water companies supplying water to London have always been amongst the leaders in their low levels of leakage with levels amongst some of the lowest in the world.

Whilst Thames Water's performance has improved substantially over the last decade since that enquiry with leakage reducing from the level of 915 Ml/d in 2004/5 to the level of 644 Ml/d in 20[xviii]13/4, climate change makes the management of this more difficult as the more extreme weather linked to the presence of a clay soil leads to an increasing amount of ground movement which in turn reduces the life of the pipes. This will also be a problem for the other water companies who also have much of their water distribution network within the area of London clay.

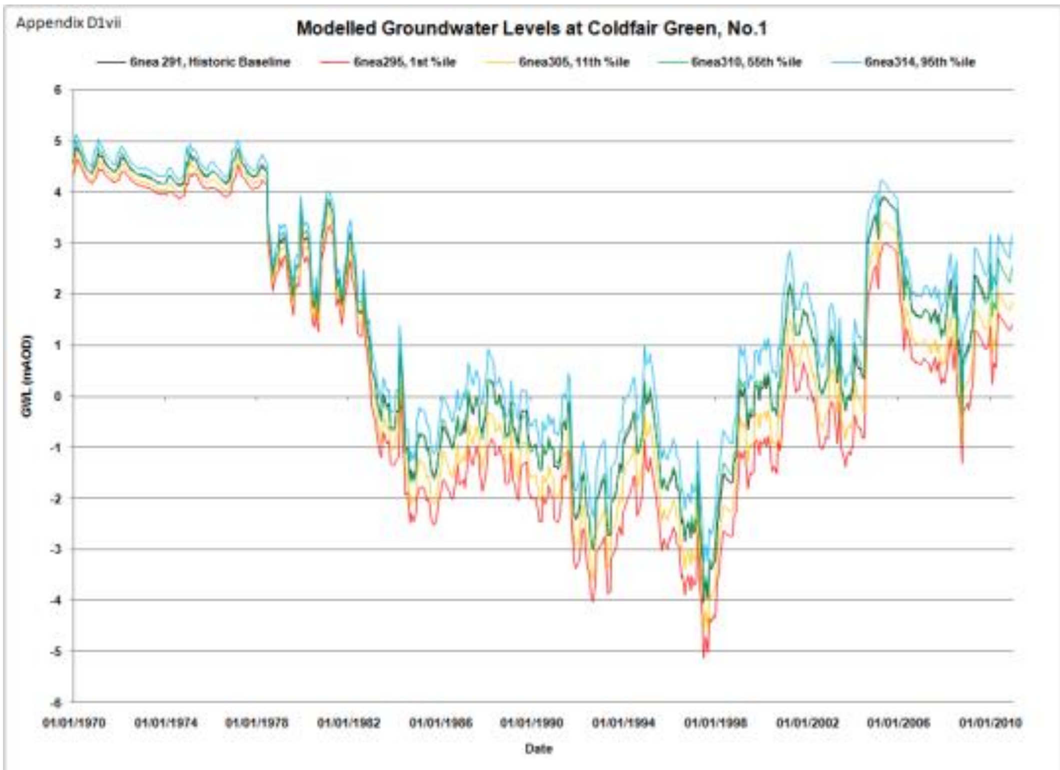
Reduced availability of water supplies

A number of factors arising from Global Warming and climate change affect the availability of water resources in London. Thames Water's Water Resources plan for 2014 shows that deployable output will reduce by around 72 Ml/d due to climate change.[xix] These projections are based on the web site UK Climate Projections with the last update used for the latest water resources plan being in 2009. It takes both river flows and the impact on ground water resources into account.

The Water Available for use (WAFU) for Thames Water is estimated to reduce from 2079 Ml/d in 2014/5 to 2029 Ml/d in 2024/5 and to 2002 Ml/d in 2034/5.

The other water companies serving London also report a reduction in water supplies. Affinity Water for instance attribute a reduction in supplies at 19 of their groundwater sources in the Central area, which serves much of north London, although they have not accounted for any reduction in the river source availability for their treatment plants serving west London as Thames Water are responsible for maintaining minimum river flows. Nevertheless, their overall deployable output for the Central region is predicted to decrease by 20 Ml/d by 2035. Whilst some of this reduction is to ensure that legislation such as the habitats directive are observed by e.g. reducing abstraction from groundwater sources close to sensitive rivers dependent on flow from groundwater, there can be no doubt that climate change will reduce the amount of water available for abstraction in the London basin.

In all these cases it is necessary to consider various scenarios and to decide which scenario to use for water resource planning purposes. Essex and Suffolk also carried out predictions with the figure below demonstrating he impact of various scenarios on the groundwater levels of one of their sources.

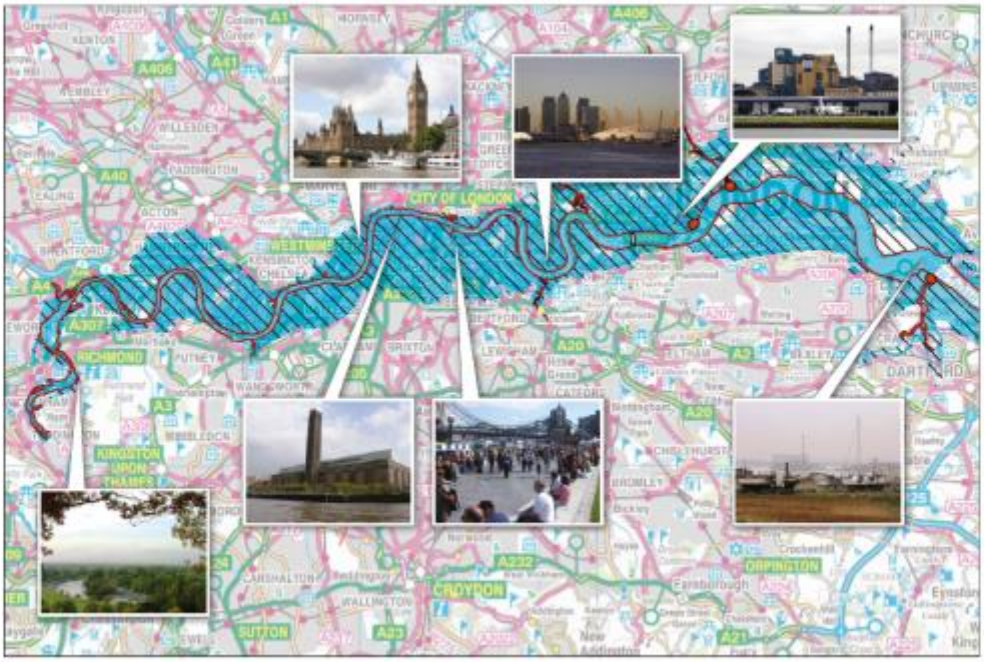


Source. Essex and Suffolk Final Water Resources Management Plan 2014

Flooding

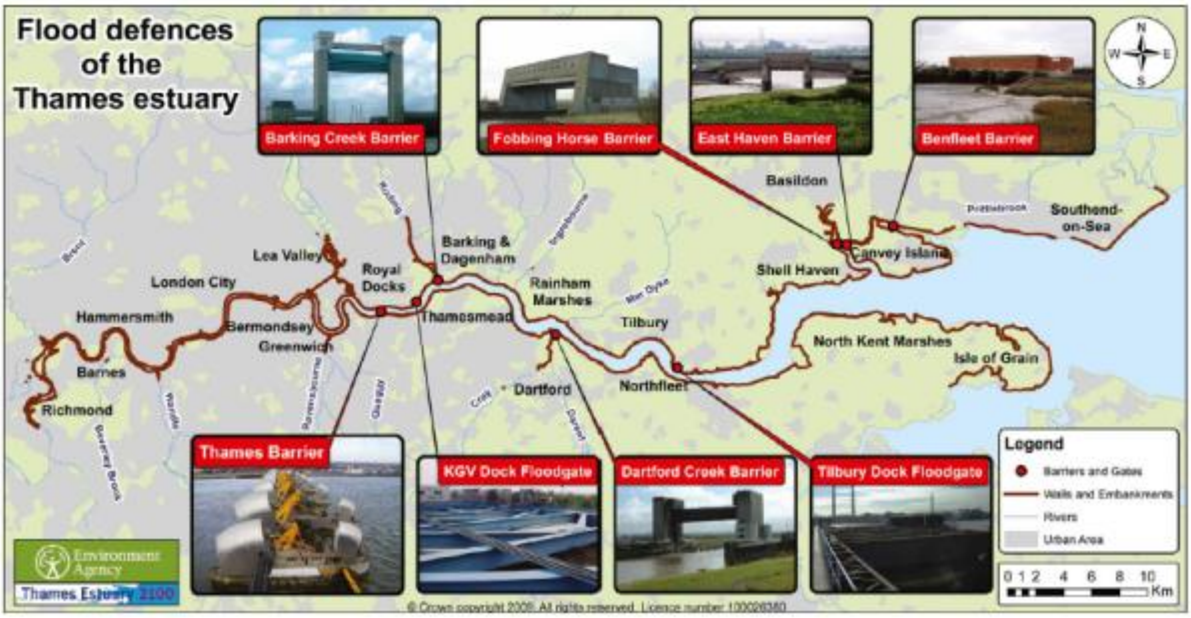
The GLA's second version of its London Strategic Flood Framework[xx] states ' Flooding is one of London's greatest risks. Two of the four "very high" risks in London's community risk register are "Severe inland flooding affecting more than two regions" and "Local urban fluvial or surface water flooding". Another five categories of flooding are classified as "high risk", including tidal flooding.' It goes on to say that approximately 15% of properties in London (just over half a million) are at risk of flooding in London from tidal and fluvial sources. London has a high proportion of basement flats and houses which are particularly vulnerable to flooding and can flood very rapidly.

In addition to residential and business properties, there are numerous public buildings, transport hubs and networks, and critical infrastructure at risk of flooding. The Environment Agency's "at risk" list includes the Houses of Parliament, Whitehall, City Hall, Canary Wharf, Westminster Abbey, the Tower of London, Kew Gardens, the O2 Arena, 51 railway stations, 35 Underground stations, eight power stations, more than 1,000 electricity substations, 400 schools and 16 hospitals are also at risk[xxi]. Large areas of Southwark, Lambeth, Tower Hamlets, Hammersmith, Fulham, Wandsworth, Barking, Dagenham, Woolwich and Newham could find themselves under water, along with many settlements along the estuary in Essex and Kent.



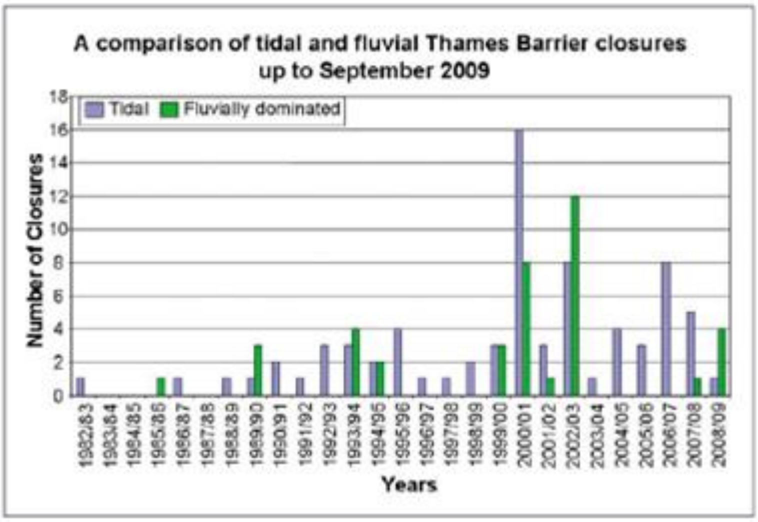
Source: TE 2100 Environment Agency 2012

This risk has been managed by embankment strengthening and by the construction of the Thames Barrier and a number of other flood barriers across its tributaries such as the Lea Barrier as shown below.



Source: TE 2100 Environment Agency 2012

There can be no doubt that the Thames Barrier has fulfilled its purpose However, from early December 2013 to the end of February 2014, its steel gates were closed a record-shattering 50 times, preventing the river from running riot. Previously, the barrier had closed only 124 times since it began operating in 1982. The EA described this sharp increase in demand as a “blip” and, apart from routine testing, the barrier hasn’t been closed since. However, during its lifetime there’s been a strong, overall upward trend: it was closed four times in the 1980s, 35 times in the 90s, and 75 times in the 2000s. There have been 65 closures since 2010, suggesting this climb is continuing. A graph of its operation is shown below:



Source: TE 2100 Environment Agency 2012

In order to inform their report referred to above and ensure their plans for flood prevention into the next century are sufficient, the EA have taken climate change into account and consulted with the UK Met Office and other climate change experts. In turn the calculations have been used to inform UKCP09 and the Intergovernmental Panel on Climate Change (IPCC).

It was thought that climate change would lead to increases in sea level, storm surge height and peak river flows. From the study, it was estimated that the sea level rise in the Thames over the rest century due to thermal expansion of the oceans, melting glaciers and polar ice is likely to be between 20 and 90 cm. Climate change is less likely to increase storm surge height and frequency in the North Sea than originally thought and in fact increases in water levels have been reduced from an increase in 4.2m to 2.7 m. Nevertheless, it is a substantial increase in level. Future peak freshwater flows in the Thames at Kingston could increase significantly by as much as 40% by 2080.

Sewer flows

As explained earlier, much of the sewer system in London was originally installed during the 19th century. By the time Bazalgette started work, most of London’s rivers and streams were carrying both sewage and rainwater. Even at the time of construction, separating the two would have been almost impossible and so Bazalgette designed his new sewers to perform the dual function of dealing with 'foul' sewage and surface water run-off. After heavy rainfall the flows were greater than his sewers could take, so he designed the system to overflow into the River Thames when necessary, to prevent sewage from backing up and flooding streets and buildings. Bazalgette's sewerage system was constructed with 57 combined sewer overflow points along the tidal River Thames. Of course, at that time, the river was 'dead' and his system was bringing big improvements, even though it overflowed from time to time.

When the sewers fill to capacity after heavy rainfall, any excess sewage is discharged into the river via these overflows, to prevent flooding to buildings and streets. Around 39 million tonnes of untreated sewage is discharged annually, and as little as 2mm of rainfall can trigger a discharge

When Bazalgette's network was built, the capital's population was around 2.5 million. He planned for population growth of around four million, not the eight million we now serve or that so many green spaces would be concreted over, preventing natural drainage. Today, the system is struggling to cope with the demands of 21st century London, and discharges are now happening much more frequently - around once a week on average. It is no longer acceptable to allow the overflow to go straight into the river. This problem will be exacerbated by climate change as rainfall becomes more intense.

In addition, the sewage treatment plants which were subsequently constructed to ensure untreated sewage did not flow into the rivers and which have been responsible for the huge improvement in water quality within the river Thames, can only deal with a certain flow. When storms increase that flow the excess is diverted to storm tanks for containment until after the storm is finished. With increasing intensity of rainfall, the storm tanks have insufficient capacity and overflows at the sewage treatment plants become more of a risk, again increasing the risk that the hard won improvement in river quality will reverse.

Energy and Carbon Footprint

The increase in need for pumping and treatment brought about by the higher demands and increased rainfall intensity will in themselves increase the demand for energy across all the water companies serving London.

The UK is currently on track to outperform the first two carbon budgets, largely reflecting the impact of the recession. But the underlying rate of emissions reduction due to low-carbon measures was less than 1% in 2011. Meeting future carbon budgets will require reducing emissions by at least 3% a year. Speeding up progress across the economy will be necessary in future[xxii].

Economy-wide greenhouse gas (GHG) emissions fell by 7% in 2011 to 547 MtCO2e. However, only around 0.8 % of this resulted from implementing emissions reduction measures. 3% was due to the mild winter temperatures in 2011. Much of the remainder was related to rising energy prices, falling real income and transitory changes in the power generation mix. There is clearly a need for all organisations in the UK to work to reduce their carbon emissions.

In addition, along with other organisations in the UK, the water companies, the EA and local authorities recognise the need to reduce their energy use and carbon footprint. In some cases, this can be a considerable quantity. During 2013/14 Thames Water's carbon emissions totalled 739 KtCO2e. Increased electricity consumption in 2013/14 from the previous year occurred due to increased pumping and treating of wastewater. This has been impacted by significant rainfall and flooding during the year. This demonstrates the impact of rainfall and flooding which will be heightened by climate change.

CHAPTER 4
Innovative responses to the climate change challenge

Introduction

It is nothing new for London's water management to be a showcase to the rest of the world. The work of Sir Hugh Myddleton and the establishment of the statutory water companies, followed by the huge projects initiated by Bazalgette-led technology at the time.

It was not just the technical challenges which were innovative. In the 1970s, the reorganisation of the water industry into organisations based on river basins managing the whole water cycle was a world first. The following privatisation introduced a different model to that used in other countries with the tri-partite regulation provided by Ofwat, the DWI and the EA being used as a model in other countries.

With the challenges of such a large metropolis it is not surprising that new developments in the London area have been necessary. In some cases, the technology has been in use in London for some time. The Thames Barrier has used a number of novel solutions in its operation and will continue to be an important part of London's flood defences.

Much of the technology used to monitor and renovate the ageing sewer and water networks has been in use for some time, including CCTV, trenchless technology such as relining and pipe bursting as well as leakage location technology such as leak noise loggers and correlators. The Thames Water Ring Main, although it has now been commissioned for over 20 years was a new approach to distributing water which is still

novel. It enabled the ageing iron water mains to be run at lower pressures, extending their life considerably.
Managing the scarce resources has required management techniques such as including conjunctive use (the balancing of river flow abstraction with groundwater abstraction to preserve resources), trunk network modelling and aquifer recharge before these techniques become more widespread. The North London Artificial Recharge Scheme (NLARS) uses a chalk aquifer beneath Enfield, Haringey and the Lee Valley which is topped up with treated water when rainfall is plentiful to use as a back-up resource to boost supplies during droughts. Finally, for renewable energy, the large sewage works have been used to generate heat and power which has been used to reduce inputs required for treatment for some time.

However, the impact of climate change will require a wide range of innovation which will require news ways or thinking and working. Some of these new approaches are detailed below.

Changes in communication and customer engagement

Partly driven by the regulator and the move to retail competition but also due to the need to explain complicated issues to customers and engage their support, it has become more important than ever to engage with all types of customers. Research into customer attitudes is being carried out both by the water companies and the organisation which carries out collaborative research on behalf of the water industry: UK Water Industry Research (UKWIR) In particular a report recently produced by UKWIR: Post PR 14 Customer Engagement, Communication and education[xxiii] was commissioned to enable the industry to take stock, collectively, and evaluate companies' programmes of customer engagement encompassing pure research, wider consultation approaches and customer communication via education programmes and campaigns. The report includes 6 principles of good practice and guidance from companies in developing and undertaking customer engagement in the future as well as for CCGs in reviewing these activities.

Other work has been done to understand how better to explain the need for metering to customers who for so long have regarded the access to unlimited treated water as an absolute right. Some sensitive subjects have been dealt with such as what should or should not be thrown into toilets or poured down the drain as the reduction of unsuitable debris being thrown into the sewers could reduce the incidence of blockages and extend the life of sewers. The comparison of non-intrusive repair methods with intrusive repair methods has ensured that new approaches do not just provide short term benefits[xxiv].

One initiative by Affinity Water has won 8 'Green Apple' awards (sustainability awards) between 2000 and 2012. This is the Education Centre at Clay Lane. An area of land which had originally been identified for a new treated water reservoir but which was no longer needed has been turned into a wildlife reserve with a purpose made teaching centre.

The Education Team

- Welcomes more than 6,000 visitors a year to
- Visits over 7,000 pupils a year in schools
- Has been accredited with the Learning Outside the Classroom Quality Badge.
- Is accredited with the 'BCE Engagement Premiership Award 2012'

All activities have been risk assessed and Education Services staff are checked against child protection registers and trained in first aid. The education centre staff leads the sessions, leaving teachers free to enjoy the day and observe the children.

Advances in water resource and asset management modelling

All the water companies have had to develop comprehensive water resource models in order to develop their water resource management plans. These plans have required detailed analysis of how the resources will perform in the future which in turn has extended the knowledge of how to model for instance aquifer storage and recharge or how to allow for uncertainty in the models. In some cases, where the water resources are highly integrated, comprehensive models which look at the different ways of providing water and establish the ones which optimise cost and environmental impact have been developed.

It is expected that the asset management plans developed by the water companies will optimise the capital investment. The water resource plans have to feed into these models and different expenditure options have to be investigated with advanced algorithms delivering and comparing various options.

With the large stock of ageing assets in the capital, the need to model future behaviour of assets has been essential. Mains and sewer deterioration models have been in existence for some time but as evidence increases these are becoming more sophisticated and allow assessment with a finer granularity in spite of the huge stock of assets. The need to consider all asset expenditure based on actual data rather than on expert opinion as was the case in the past has required the development of approaches which can be applied to the large structures which have a low probability of failure but a high impact in the case of such a failure[xxv].

Localised recycling and building improvement

A number of developments in London have used recycled water. One land mark property which spearheaded this approach was the millennium dome. Thames Water approached the New Millennium Experience Company (NMEC) suggesting a collaborative effort to develop an innovative approach to water management on the site of the Millennium Dome in Greenwich. The main objectives of the project included demonstrating and researching water recycling technologies, evaluating water efficient appliances and investigating public attitudes to water recycling initiatives. The system was in use during the lifetime of the 'Millennium Dome experience' with Thames Water research scientists evaluating the approach to allow lessons to be learned for the future.

The surface area of the Dome itself is some 90,000 m^2. Rainwater run-off from the roof is collected via a gutter and channelled through specially designed hoppers, which feed into the surface water drainage system. A maximum of lOOm2/day can be collected in this way.

View of the entry to the rainwater storage system

Grey water was collected from the hand basins and staff showers from the Dome's six core buildings. The expected visitor numbers were predicted to use on average 120 m^2/day of hand basin water. London has had a problem with rising groundwater since 1970 due to a decline in pumping rates, caused by the changing industrial and commercial base. A 110 m borehole was drilled on the site and water pumped direct from the aquifers.

A range of treatment options were available. The Dome provided the opportunity to implement a re-use scheme at full scale and demonstrate the full range of innovative treatment options. Since the rainwater run-off was collected swiftly and thus uncontaminated, open reed beds were an appropriate choice. An arrangement of educational boards and a walkway running through this landscape allowed the general public to understand the operation of this 'natural' form of water treatment.

The primary concern in treating grey water is to meet the quality criteria for pathogen kill. Another key concern is ensuring minimal potential for biological regrowth in the reclaimed water. Thames Water Research carried out a range of pilot scale trials using biological aerated filters (BAF) followed by a variety of membranes with specific emphasis on soluble bio-chemical oxygen demand (BOD) removal using synthetic grey water. Another consideration was dealing with modern soaps that would be contained in the grey water discharge. The trials indicated that tight ultra-filtration membranes were the most appropriate for hand basin and shower grey water.

Water from the borehole was tested to establish the groundwater quality. A problem with hydrogen sulphide gas was experienced together with a much higher than anticipated salt and iron content. A system was devised to dose the groundwater with hydrogen peroxide to oxidise any metal contaminates, then pass the water through granular activated carbon to remove the organic contaminates. Membrane filtration followed carbon exchange where ultra-filtration removed residual organics and a reverse osmosis (RO) membrane desalinated the groundwater. As RO filtration was needed to remove the salt from the borehole water, it was therefore combined with the BAF treated grey water and rainwater from the reed beds through the same membrane configuration. The treated water was then re-hardened and disinfected before being pumped back into the Dome for flushing the WC's and urinals.

A domestic development which was designed with a wide variety of sustainable approaches was ‘BedZed’ (Beddington Zero Energy Development) in the London Borough of Sutton. This incorporates a wide variety of sustainable approaches and comprises 100 homes, community facilities and workspace for 100 people. Residents have been living at BedZED since March 2002.

A view of Bedzed

The learning from these projects has enabled the Olympic Development completed in East London to contribute to the most sustainable Olympics ever held. The London Legacy Development Corporation is monitoring the future use of the site and continues to promote sustainability. This covers all aspects of sustainability such that the site is an example for the future of the city. The initiatives to manage the water cycle have covered a wide range of innovations.

A 24 % water efficiency saving was achieved across the Olympic venues through fixtures and fittings alone. This has the potential to rise to 57% through existing planned potable water substitution measures[xxvi]. The park itself uses 40% less water than design standards for similar venues. The London Aquatics Centre uses 32% less potable water compared with other swimming pool centres. This is achieved by using low flow fittings, rainwater harvesting and recycling water. While low flow showers, taps and low flush toilets contribute most to the savings (29%) overflow water from the pools is used for toilet and urinal flushing providing an additional 3% reduction in potable water use.

The new homes in Chobham Manor incorporate water efficient fittings and the plant species chosen require less water than average. This means that the homes meet a standard of 90 litters per person per day (lppd) compared with the requirement in the current building regulations of 125 lppd and well below the current national average of 142 lppd.

The Old Ford Water Recycling Plant uses advanced water treatment processes to recycle sewage for irrigation and toilet flushing. It currently just provides water within the park but the corporation are looking at ways in which this can be extended to properties outside the park, particularly once the initial watering required to establish the plants within the green open spaces reduces. The Corporation also looks after the rivers and waterways through the park which provides a programme of use for leisure, transport, education and tourism.

The corporation works with venue operators to encourage the public to bring more reusable water bottles along with the provision of water fountains to reduce the quantity of bottled water used.

New Interceptor Sewers

The problem of sewer overflows described above is not an easy problem to solve. As with the Thames Water Ring Main the company has opted for a solution which uses the underground space and the suitability of the geology for tunnelling.

The £635m Lee Tunnel will transfer any discharges from London's largest combined sewer overflow at Abbey Mills pumping station in Stratford to Beckton sewage works, the capacity of which is being expanded by over 60%.

Construction is well under way on the Lee Tunnel, which will help prevent more than 16 million tonnes of sewage entering the River Lee each year. In January 2014, the tunnelling work on the Lee Tunnel was completed and the project is on target to be completed by the end of 2015.

The Lee Tunnel received two awards from the Institution of Civil Engineers at the annual London Civil Engineering Excellence Awards. The project received the overall award for the Greatest Contribution to London in March, beating a shortlist of 13 other infrastructures and building projects. It recognises the significant benefits the tunnel will bring to the capital when it is completed in 2015 and eliminates 40 per cent of the total annual sewage discharges to the River Thames.

The proposed Thames Tideway Tunnel will address discharges of sewage into the Thames. It will be 15 miles long, and will be one of the longest and deepest tunnels under London.

The planning processes were completed during 2014. Construction on the project is expected to start in 2016 and take around seven years to complete.

Control of Rain Water Flooding

Drain London, initiated by the GLA, is leading a partnership of 33 London boroughs, the Environment Agency, Thames Water and Transport for London. It also works with other bodies that have drainage responsibilities in London through the Drain London Forum. The Drain London programme helps to predict and manage surface water flood risk in London. Drain London is improving our knowledge of the surface water drainage system and identifying those areas at most risk of flooding. It is also trying to find ways to reduce flood risk. It was created in response to the Mayor's Regional Flood Risk Appraisal, which identified surface water flood risk as the most likely cause of flooding in London.

Flood risk modelling through Drain London has helped London's boroughs to better understand the risks in their borough and to produce a Surface Water Management Plan to help manage and reduce those risks. Drain London is also working on several projects that show how surface water can be managed in a more sustainable way. This includes converting impermeable surfaces into green permeable surfaces, diverting rainwater pipes into landscaped areas and restoring river corridors to absorb more water.

Control of fluvial and tidal flooding

The policy of the EA for managing flooding in the Thames Valley through London is encapsulated in the document TE 2100(xxi). At first sight the document may not look to suggest anything very innovative. However, this advocates careful monitoring of a range of indicators along with a collaborative approach and an assessment which considers both the basin as a whole and sectors of the basin. It therefore requires a sophisticated information system which has been developed by the EA. This is in parallel to a highly developed River monitoring telemetry system which also links to a sophisticated modelling for the whole river which allows both short and longer term risk to be assessed and reviewed.

This approach has the advantage of minimising construction work, relying on a more cohesive approach rather than the development of yet more expensive control, structures which have a major carbon footprint themselves. It also allows for the inevitable variations in the actual impact of climate change with regular reviews as time progresses.

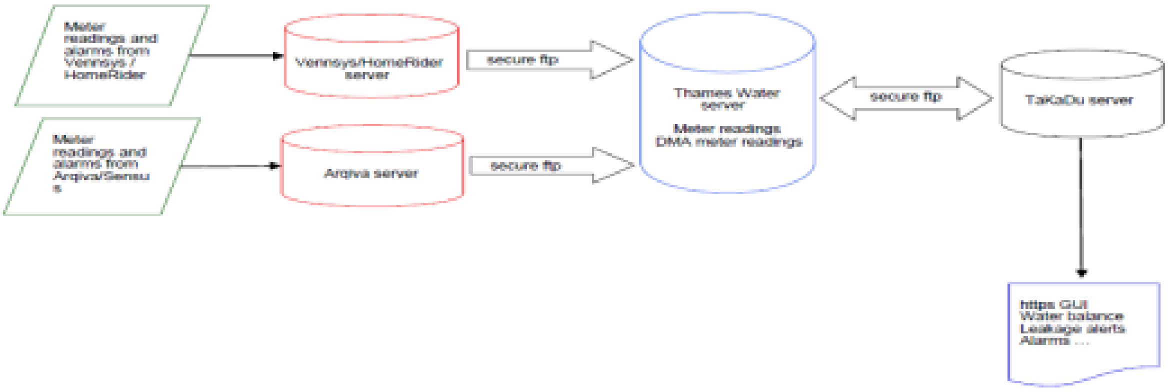
Water Resource Management

The balancing of supply and demand cannot rely purely on demand side measures such as those described above. Inevitably London will require new resources, although any major development will not be required until the 2020s, which in itself is a substantial achievement, given that London is one of the driest capital cities in the world. The last new resource to be developed was the desalination plant at Beckton. This optimised the treatment required by using water on the ebb tide when the saline content was lowest and discharged waste had the least impact.

For the future, Thames Water is looking at various reuse and transfer options along with further ground water recharge similar to that already used with NLARS. As with the flooding, this approach, using detailed modelling and planning and small local actions, whilst not necessarily gaining the notice of the media, can provide more flexibility and a lower carbon impact than a single large scheme. In the longer term however a major new raw water storage facility may be required.

Reduction in leakage

An important part of managing he supply demand balance is to ensure that leakage from water pipes is minimised. As explained earlier. London's distribution network is one of the oldest in the world. Thames Water has already trialled a complete 'Smart DMA' with extensive instrumentation. This is now being extended to include smart customer metering giving a near real time water balance. The network is the first of its kind in the world[xxvii].



The Thames Water 'smart network' (Source Swan UK Conference 2011)

Wholesale replacement of the water main network is also being carried out. This uses a variety of trenchless techniques wherever possible to minimise disruption and has promoted the development of collaborative working between Thames Water, the London Boroughs and Transport for London.

Conclusions

The challenges for managing the water cycle and providing water services in London have exercised some of the greatest UK engineers for centuries. Innovative approaches are nothing new to the city and have ensured that Londoners have enjoyed a continuous supply of water and have avoided the problem of flooding throughout most of the 20th and the 21st century to date.

The organisations in the capital responsible for aspects of the water cycle continue to work together to review the issues and provide innovative solutions whilst respecting London's unique history and culture.

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