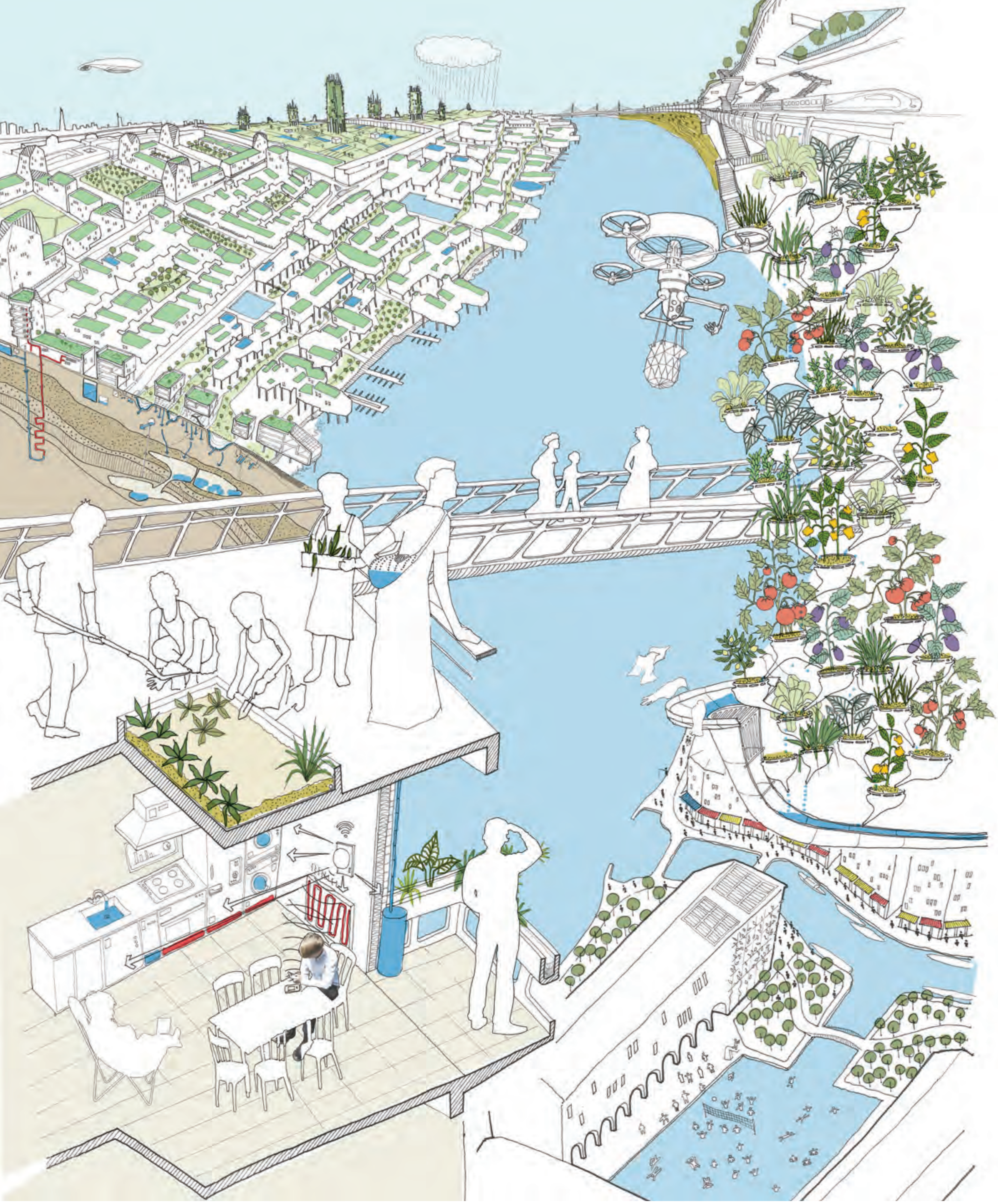

Future Visions for Water and Cities

A Thought Piece

THE UK WATER PARTNERSHIP

Submitted to the Expert Group of the Foresight 'Future of Cities' Project by the Water and Cities Action Group of UKWRIP now the Research & Innovation group of the UK Water Partnership, led by the Natural Environment Research Council on behalf of Research Councils UK.

April 2015

This paper has been prepared by UKWRIP's Water and Cities Action Group at the invitation of the Expert Group advising the current Foresight 'Future of Cities' project. The project is identifying the opportunities and challenges that UK cities will face in future and need to embrace in order to be resilient, to be adaptable and to thrive.

UKWRIP is a collaboration between the water industry, policy and research communities, providing guidance and co-ordination for water research & innovation in the UK. UKWRIP has now become the research and innovation arm of the UK Water Partnership, launched February 2015.

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Executive Summary

Where water provision and use are concerned, the cities of the future will face a whole range of major challenges.

These revolve around the ability not only to meet fundamental needs in terms of water supply, wastewater treatment and drainage services, but also to safeguard water's many indirect benefits in spheres such as health, wellbeing and biodiversity. Moreover, these goals need to be achieved while protecting the wider environment and ensuring cities' resilience against extreme events such as flooding.

Key to meeting these challenges is the development of a clear picture of the many ways in which water use, needs and resilience could be addressed in future cities, and what still needs to be done in the field of research for such possibilities to be realised.

As a starting point, this paper sets out five different, non-exclusive visions that provide examples of how cities might potentially be tackling the issue of water cycle management in the year 2065:

- **Vision 1 – Green Food & Garden Cityscapes:** More food is grown both in and on buildings, while water-sensitive urban design management plays a pivotal role.
- **Vision 2 – Flood-proof Cities:** Existing cities and new city areas floating on stilts are designed to withstand sea-level rise, extreme rainfall and expansion of river floodplains.
- **Vision 3 – Smart Homes & City Networks:** Using the internet, appliances, networks and data-hubs interact to ensure optimal management of water supply and demand.
- **Vision 4 – Cities & the Underworld:** Deep geology beneath cities is harnessed to house combined systems delivering effective drainage, water, heating and cooling services.
- **Vision 5 – Community Transition Cities:** Utility-run programmes change communities' water-related habits and practices by 'transitioning' these to a more sustainable level.

Realising such visions will mean ensuring that the necessary technologies, capabilities, processes and practices are not just made feasible but also become available on the required timescale. This, in turn, requires the effective tackling of a range of underpinning, often interconnected challenges not specific to any one vision but applying more widely to the ability to set cities' water use, needs and resilience on a secure future footing.

In this paper, eight such challenges are pinpointed, together with a selection of current/recent research & innovation initiatives and some of the key questions that still need to be addressed in each area. The challenges are:

- **Water Quantity/Quality for Life, Health & Leisure** – embracing the most fundamental water needs of urban communities and recognising that freshwater sources within cities may be insufficient to keep pace with 21st century population densities.
- **End-user & City-dweller Behaviour/Demand** – focusing on the need to use water more efficiently and to cut overall demand if possible, especially in view of anticipated strains on water supplies due to growing populations and climate change.
- **Infrastructure: Above Ground** – assessing whether 'small is beautiful' or 'big is best' and whether centralised or decentralised arrangements represent the most effective, most efficient approach to providing water services for cities.
- **Infrastructure: Below Ground** – considering how infrastructure systems buried underground interact with the natural environment and understanding the stresses involved and how these can impact on system performance.
- **City Groundwater Management** – encompassing the function, governance and sustainable management of groundwater in an urban context and recognising how water resources are supplied from a wider catchment area extending beyond city boundaries.
- **Risk & Resilience to Extreme Events** – understanding the risks cities face in terms of all kinds of extreme natural and manmade hazards and building resilience against them, especially in the context of climate change and its anticipated impact on rainfall patterns.

- **Environment & Ecosystems** – evaluating the impact that future cities will have on the wider environment, particularly in the context of the potential need for greater reliance on local provision of goods/services and the resulting requirement to protect local ecosystems.

- **Cross-cutting Issues & Whole-system Approaches** – recognising that many issues relating to water management are not specific to one particular aspect of use/provision and integrate drivers and impacts originating well beyond the water industry and water science.

Alongside research initiatives designed to further develop understanding and capabilities in each of these eight areas, city simulators and city demonstrators have a potentially valuable role to play in developing, testing and evaluating innovative ideas that could help shape the evolving relationship between water and cities:

- Still at a very early stage of development and application, computer simulations using cities as 'living laboratories' could help to target research resources at key issues (e.g. demand and pricing for a range of services and commodities).

- Real-life community-scale city demonstrators could, for example, focus on smart homes/networks, robotic repair technologies, urban agriculture, sustainable drainage and floating cityscapes.

Based on the discussion and analysis presented in this paper, UKWRIP has framed a series of four recommendations for further consideration by the Foresight 'Future of Cities' project as the next steps in addressing the challenges that cities face:

1. Encourage the use, refinement and augmentation of the visions included in this publication, adapting them where needed, in order to engage with city authorities and help them develop their future city plans.

2. For each of the eight underpinning challenges, note the gaps highlighted in this publication as a result of synthesising past research outputs, and encourage further review and assessment of existing and planned research to see how those gaps are being addressed.

3. Promote further engagement between relevant researchers and users of urban research in order to translate research outputs into targeted outputs for users (planners, policy-makers, businesses, community organisations etc.).

4. Support the development of funding opportunities for research & innovation through the UK Research Councils, Innovate UK, business partners (e.g. water utilities and consultancies) etc., via multi-disciplinary programmes, city simulators and city demonstrators.

1. The Purpose of this Paper

Water is a vital resource that is too often taken for granted. Individuals, infrastructure and industry all have a range of fundamental water-related requirements that encompass supply, wastewater treatment and drainage services. Meeting these direct needs – while ensuring resilience against extreme climate-related and other events – is a major challenge facing the cities of the future.

Nor should water's many indirect benefits – for example, to leisure, recreation, health & wellbeing, biodiversity and urban ecosystems – be overlooked or underestimated. When planning for future cities, an authentically holistic approach is essential if our dependency on water and the need to protect the wider environment and vital natural assets are all to be accommodated effectively.

The challenges may be substantial. But so are the possibilities. Water use, needs and resilience could potentially be addressed in many different ways. The purpose of this paper is to set out some of those possibilities and to ask a crucial question: how close are we to making them achievable and what insights do we still need to secure in order to bring them within our reach?

The paper **focuses on five distinctive visions** of the future relationship between water and cities. While neither exhaustive nor mutually exclusive, these visions highlight intriguing examples of future-proofing from a water perspective. Then, while recognising the many interdependencies and linkages that characterise water use, the paper: **assesses eight key challenges to be tackled** if such visions are to be realised; **summarises current/recent research** relevant to each of those challenges; and **pinpoints gaps in understanding** that must be addressed if the potential is to be truly unlocked.

Supertree Grove, Singapore, courtesy of Gardens by the Bay

2. Water and Cities: A Fluid Relationship

In UK cities, water infrastructure is estimated to be worth nearly £400 billion[1]. Globally, the OECD estimates that water will soon make up the lion's share of infrastructure investment. For just OECD countries and Russia, China, India and Brazil, water spending in 2025 will top $1 trillion - nearly triple the amounts needed for investments in electricity or transport (World Bank 2012). The scale of these figures underlines the critical relationship between water and cities, and the pivotal role that water plays in cities' success. Moreover, in view of the development of new technologies, on the one hand, and the emerging challenges posed by climate change and population growth, on the other, this relationship will inevitably continue to evolve as the 21st century unfolds.

- The fundamental building block of any city is the human being. Each day, every person needs at least 2 litres of fluids and food containing freshwater, and excretes 1-2 litres of urine (WHO website). In high-income countries, however, each city-dweller's typical daily use amounts to 100-250 litres of freshwater – in the UK, the typical figure is 150-165 litres (Defra 2008; Thames Water 2015).

- The nature of the built environment means that cities affect the natural water cycle in other ways too. For instance, urbanised catchments are often more subject to flash-flooding than their rural equivalents (Robinson *et al*. 2000; White 2010); this is due to the way rainfall is received by impermeable surfaces/structures (e.g. concrete driveways) and drainage processes in such catchments.

- Cities may also be subjected to groundwater, river, surface water and coastal flooding produced by the wider environment. Around the world, the majority of cities are located towards the lower end of river catchments and in coastal areas, often making them vulnerable to all these types of flooding, sometimes in combination (Huntley *et al*. 2001).

- Population densities in 21st century cities range from 1000 to 40,000+ people per km^2 (examples - Dakha 43,000; Delhi 12,100; Shanghai 6100; London 5900; New York City 1800) (Demographia 2015). Between 80-90% of the UK population now live in urban areas and these now cover around 7.5% of the land area of England and Wales (Office for National Statistics 2011).

The facts set out above provide just a flavour of the challenge facing cities in terms of effective provision of water-related services and protection against destructive natural events. On average, annual global rainfall amounts to 1 million m^3 per km^2 (NOAA 2013); if a city area could capture and store 100% of its rainfall, it could, in theory, sustain a population density of 10,000/km^2 at current water usage levels, without recycling[2]. But not only might this leave less water for the environment and for leisure users, the practicality of achieving such a capture/storage level is also questionable.

Clearly, the search for viable, acceptable solutions to water cycle management in the cities of the future needs to harness a high degree of imagination, creativity and a willingness to think 'outside the box'. In short, it demands 'vision'.

[1] Derived from 2014 regulated base value of £261 billion using Ofwat RPI figures (Ofwat 2010 and website) plus coastal and flood asset value of £102bn (Environment Agency 2014) + 10% addition from Scotland and Ireland (proportional population) + an estimated £2000 for plumbing and drainage infrastructure for circa 25 million domestic premises (£50 billion) = £450billion. 85% for urban population gives £380 billion.

[2] UK domestic water usage of 165l/person/day equates to 60m^3/person/per annum. A population density of 10,000 per km^2 therefore requires 0.6 million m^3/km^2/annum for domestic purposes or 60% of global average annual rainfall of 1000mm per annum (1 million m^3/km^2).

3. Five Visions of the Future

Fifty years from now, in 2065, how might cities be ensuring, safeguarding and managing their water needs, use and resilience? Developing a picture of the possibilities and potential is an essential step to ensuring that the necessary technologies, capabilities, processes and practices become feasible and available on the required timescale.

As noted in Section 2 above, it is evident that there will be a need for innovative, agile, versatile solutions that address a wide range of issues and criteria. This section sets out a suite of five different visions that could potentially help to deliver such solutions. It is important to note, however, that:

- Many of the individual ideas and philosophies embodied in the following visions could combine with and complement each other, dovetailing together to provide cities with multi-faceted, multi-dimensional answers to key water-related challenges.

- These visions only comprise exemplars, not an exhaustive list of all the possible approaches that could contribute to future-proof cities with respect to their water requirements.

Vision 1: Green Food & Garden Cityscapes

Key Concept: More food is grown in cities, both in and on buildings. Water is subject to a highly monitored, highly managed 'system of systems' spanning city, catchment and underground geology, ensuring climate-resilient drainage, food production etc. Water-sensitive urban design management helps to underpin this vision.

Main Features:

- Planning permission for large buildings/developments requires 100% rainfall capture and recycling for use in the building, or sale of surplus processed water to other city functions (e.g. greenspace irrigation, hydrogen production for vehicles).
- New suburban low-rise building developments are also required to incorporate 100% rainfall capture and reuse, complemented by water storage, solar thermal and PV systems and integrated green-roof surfaces (e.g. see today's 'BedZED' housing development in London).
- Water-sensitive designs incorporate drainage and rainwater collection systems integrated with bio-diverse greenspace parks, allotments and (if suitable) artificial groundwater recharge.
- Roof gardens, street allotments, food-crop, urban livestock farming and alternative agri-food networks (AAFNs) and ecosystem parks are popular and widespread. Urban aquaculture also thrives.
- Packaging/food waste is bio-recyclable in community-scale composting & anaerobic digestion plants linked to combined heat & power systems and 'tropical hot-house' food production.
- Local-produce food markets are developed close to food production areas, with new trading models for allotment owners and income opportunities for the active, ageing population.
- In larger buildings/developments, food and plant waste are recycled via in-basement composting & anaerobic waste/wastewater processing systems producing biogas and electrolysed water for hydrogen vehicle fuel, and recovering fertiliser materials for city farms.

Allotments
Vertical farming

Roof gardens

What It Looks Like/How It Works:
Eden Project-style 'city farms' in Dome- and Shard-like structures are prominent, but with space for apartments and offices. Buildings are of atrium-style design with external surfaces capturing sunlight/rainfall for lighting, heating, power and water uses. Internal atriums stretch for the full height of buildings and provide wall/floor surfaces and irrigation systems for growing plants tended and harvested by robotic and drone systems. Basements include large rainwater storage and recycled water processing tanks and farms artificially illuminated by LED and light-pipe technology. Networks help inform food growers how to produce plentiful, safe food, free from pollutants, pathogens and pests.

Technical Aspects:
Technologies include: advanced in-building climate control; water balance and irrigation systems; crop tailoring for vertical growth; development of robotic food-crop harvesting/processing systems.

Benefits (Examples):
This concept helps to reduce the impact of new developments on food security, with new cities developing food and water footprints equivalent to the farms they replace.

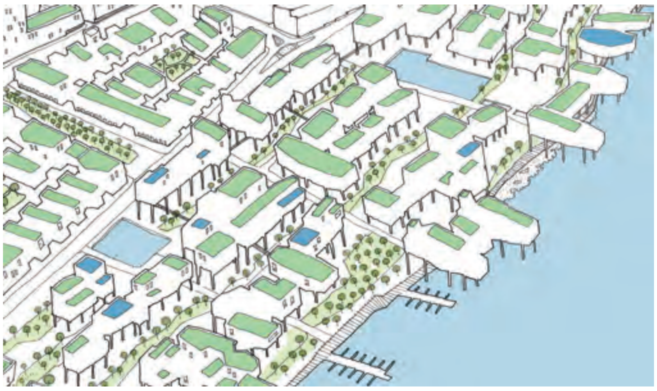
Vision 2: Flood-proof Cities

Key Concept: Existing cities, as well as new city areas floating on stilts, are designed to withstand sea-level rise, extreme rainfall events and expansion of river floodplains. Alongside engineering methods, green infrastructure and nature-based solutions help to reduce vulnerability to flooding (i.e. by interception, storage and slow release of flood waters and heavy rainfall).

Main Features:

- The 'stilts' concept means that new buildings in floodplains are designed to allow their ground-floor level to be flooded, with all below-ground services either flood-proofed or raised and incorporated into new transport corridors 5-10m above the ground.
- In-city building developments are required to accommodate a vertical 'make space for water' provision of around 5m above current high-water sea and river levels, and to incorporate smart ways of flood-proofing parts of the building around 5m above the floodplain.
- Existing low-rise buildings close to floodplains are adapted or replaced.
- Where tidal flood barrages have been put in place, they are used to reduce variations in river levels driven by tidal cycles, allowing easier development of floating city areas, flood-proof buildings, transport corridors and water-related recreation areas.
- Mega storm-tunnels (e.g. the Thames Tideway Tunnel) and larger storm drainage routes potentially provide resilience to more extreme rainfall events for cities where there is significant vertical variation in land surfaces close to or within cities (e.g. Los Angeles, Genoa).
- Communities may choose to pay upstream rural landowners to allow their land to flood (i.e. they pay these landowners for an ecosystem service) and so avoid urban flooding.

Raised infrastructure viaduct
Green roof + cycle/pedestrian network on top
Zero carbon intercity goods transport



Stilt based development
Sustainable urban drainage systems
Bio retention areas interspersed with access
Green roofs

What It Looks Like/How It Works:
Floating cities and 'cities on stilts' are complemented by elevated light-transport corridors in floodplains that cater for walking, cycling and electric city scooters, as well as ultra-light-weight electric cars and delivery vans. These corridors incorporate ducts for the utility services that buildings require. Transport by water becomes more important not just for carrying people but also for making bulky, heavy deliveries and undertaking waste collection (as in Amsterdam, Venice and cities along the Mekong today).

Technical Aspects:
Requirements include: creation, preservation and restoration of ponds, woodlands and wetlands; green roofs; sustainable drainage systems (SuDS); and permeable surfaces for domestic gardens, both in urban centres and in upstream catchments. Optimal development and siting of green infrastructure demands detailed knowledge of water flows, effective vegetation densities etc.

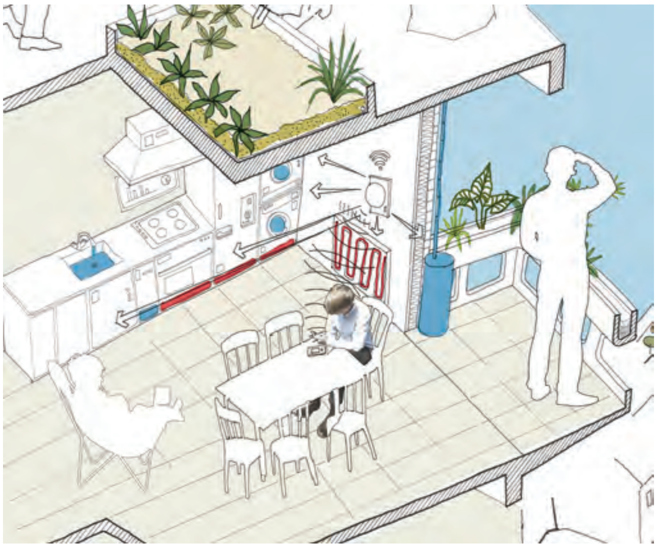
Benefits (Examples):
As well as avoiding some of the inexorably rising cost of flood barrages and levees, this vision enables the benefits of flooding to be recognised and, in some cases, harnessed (e.g. where floods kept in-channel help to maintain water quality and ecology, and flush away detritus/rubbish).

Vision 3: Smart Homes & City Networks

Key Concept: Harnessing the power of the internet, every domestic appliance used by citizens and every utility network communicates key data on current/anticipated needs, status, condition etc. to city data-hubs, which manage water supply and demand to ensure optimal efficiency and optimal economic/environmental performance.

Main Features:

- All home appliances that use water or energy communicate with smart home-hubs; these, in turn, communicate with network hubs run by local utility services.
- Hubs automatically negotiate service levels and the price of provision on the basis of time-slices a few minutes long, helping to avoid inefficient peaks and troughs in demand for and supply of water and energy services.
- Homes and other buildings incorporate systems for the local storage of water, electricity and heat, plus the means to exchange heat, cold and power between these storage mechanisms.
- Individuals carry smart watches/phones that include personal preference settings for room temperature, shower temperature/duration etc., and that keep them informed in real-time of opportunities to save money through lifestyle choices at home or in the office.
- Drainage networks incorporate intelligent switching/storage of flows resulting from extreme but localised rainfall events (as in Rotterdam today, where subsurface car parks provide emergency storage of local surface flood waters).
- Along with the monitoring of water quality, health etc., the focus of risk-related smart diagnostics (and of recommendations for actions) shifts to the point of use.



Smart central processing hub
Water capture & storage
Connected gadgets

Farm + office + residential + industrial networked communities
Local and central water management scales

What It Looks Like/How It Works:
Beyond the home, water, sewer, gas and electricity service pipes/networks under city streets incorporate embedded sensors that communicate their performance and condition, self-diagnose latent failures and request maintenance before failure occurs. Robotic road vehicles, drones and satellites use multi-spectral physics-based sensors to monitor/survey remotely the overall health of city networks housed below transport corridors.

Technical Aspects:
Improved communication and control systems play a key role. Low-dig, quiet-dig, no-dig and in-pipe robotic 'repair and replace' technologies maintain buried network infrastructure in order to ensure minimal disruption to life at street level.

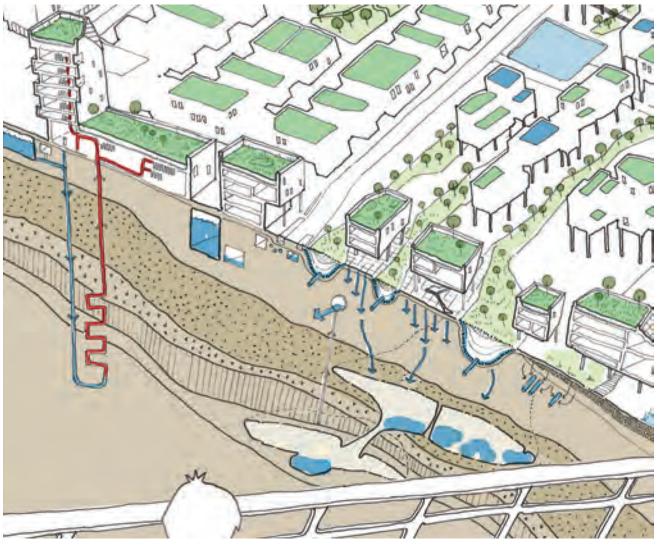
Benefits (Examples):
Although the efficiency, cost and convenience benefits are obvious, some social scientists caution against overreliance on smart technology which underestimates the complexity of human behaviour, e.g. by categorising individuals as 'normal' water users. Some argue that water savings, for example, can be negated by more resource-intensive practices (e.g. the increased power of new shower designs) (Strengers 2011). By this analysis, a water efficiency culture among individuals and communities would be needed in order to complement technological advances.

Vision 4: Cities & the Underworld

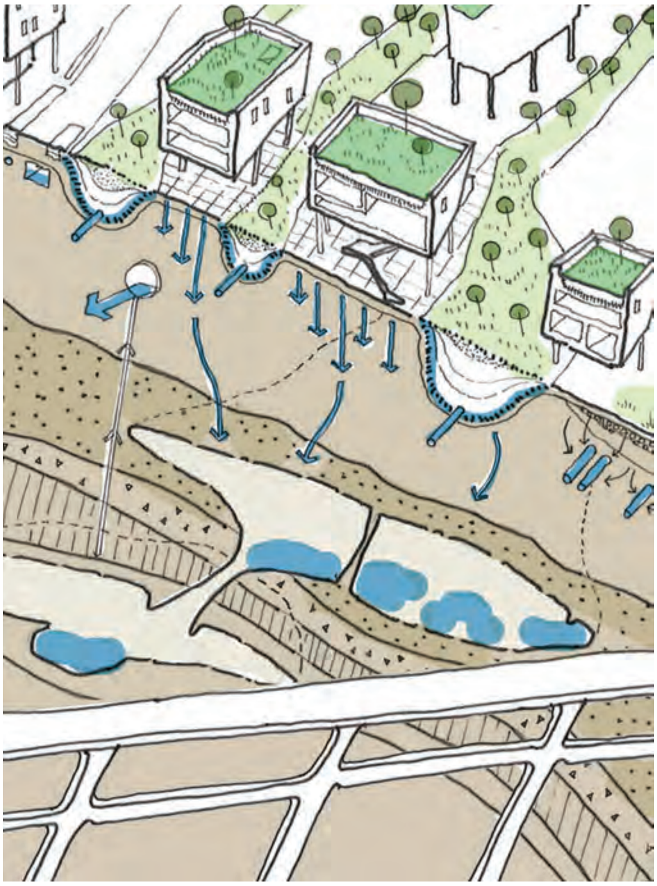
Key Concept: As functions increasingly move underneath the city and interact there too, the focus in the water sector is on how deep geology can be used to house combined systems designed to deliver effective drainage, water, heating and cooling services.

Main Features:

- Interdependent underground systems provide megacity-scale storage of water, heat and cold, and manage the exchange of fresh, saline and geothermal water as well as the recharging of aquifers.
- Water, energy and underground transport infrastructure are managed in an integrated 'system of systems' embracing everything from individual buildings to the geology located under the entire city.
- Saline groundwater is sometimes harnessed by surface buildings for the exchange of heat and cold.
- As a result of the development of building-scale and community-scale recycling models for utility services, some existing underground water and drainage networks become redundant but can be regenerated as transport ducts that deliver other services/products via their pipe space.
- During periods of low energy demand, wind-powered brackish water desalination plants recharge groundwater aquifers, using freshwater 'lenses' (i.e. reservoirs without walls) located beneath cities and nearby agricultural areas.
- Transfer of water between large underground storage facilities and above-ground storage facilities is integrated with energy storage and recovery systems.
- Integrated urban-rural catchment management takes account of multiple users, including agriculture.



Geo-thermal heating/cooling
Bio retention areas with water permeability
Underground aquifer recharge
Underground water storage



What It Looks Like/How It Works:
As today, many cities are built around brackish estuaries or coastal areas and so have access to saline surface and groundwater. The local 'underground agency' is responsible for issuing work permits to licensed repair and renewal service contractors who meet the low-dig, quiet-dig and no-dig criteria set out in the document 'Managing in the Underworld', issued by the agency.

Technical Aspects:
The three-dimensional space beneath the city requires accurate mapping, monitoring and modelling with both infrastructure and service functions in mind (e.g. groundwater recharge, heat flow). Near-surface utility networks and infrastructure need to meet 'smart' criteria (as described in Vision 3).

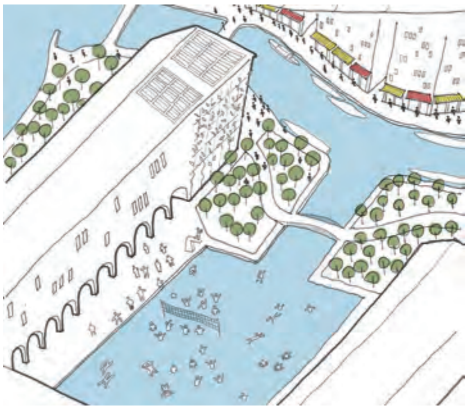
Benefits (Examples):
One key benefit is eliminating or reducing the need for large surface-water reservoirs; such reservoirs represent an opportunity cost in terms of preventing the land's use for other purposes (e.g. food production). Another is reduction in traffic disruption due to excavations to access and repair urban utility network assets.

Vision 5: Community Transition Cities

Key Concept: Concerns about water and other key resources drive a new approach to environmental governance, based on changing communities' habits and practices by 'transitioning' these to a more sustainable level. This transition is achieved through supported, utility-run programmes.

Main Features:

- The role of utilities shifts from a primary focus on resource provision to the facilitation of partnerships and improved resource stewardship.
- Water stewardship comprises two mutually reinforcing components: (i) strategic leadership; (ii) mobilisation of stakeholders and of the wider public in managing the system.
- A key goal of water utilities is to communicate the water management situation in the locality and to build a conversation with stakeholders and the wider public about the potential choices and costs (environmental, economic and social) of different investment options.
- Water utilities work in partnership with stakeholders and the wider public to help communities find new ways of achieving more efficient use of resources.
- Some of the measures and interventions taken focus on ensuring that new technical features are implemented; others revolve around a combination of technical features and social negotiation; others are purely social in scope.



Canal side retail and pedestrian-friendly development

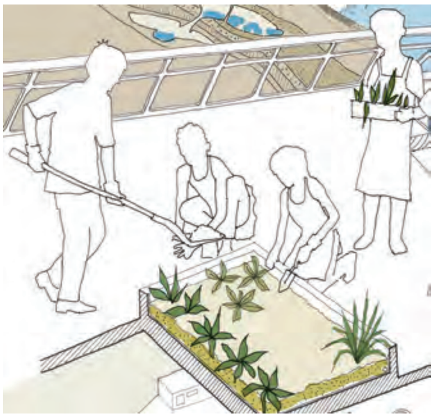
Water for leisure and sports activity

What It Looks Like/How It Works:
Utilities invest significant time and energy in developing and implementing long-term communications strategies, with resulting programmes raising and exploring the relative strengths of different options (e.g. the merits of investments in technology, rather than in trying to achieve changes in people's service expectations).

Technical Aspects:
Interventions may see utilities working with businesses and community groups to plan, implement and learn from the installation of composting toilets across a site, or a water-utility trade organisation working with toiletry manufacturers to explore how the environmental and energy costs of toiletries can be minimised. Proposals for installing a new SuDS in a municipal park may require consultation and negotiation with different sets of existing users. Water usage reduction competitions between schools may involve the installation of technical measures to cut water use as well as provision of educational packs to support the initiative. Social interventions might include water utilities offering grants for youth groups to go 'wild camping', in the knowledge that young people who experience living with limited water are better able to adjust their water use at home during times of scarcity.

Benefits (Examples):
As climate change combines with ageing infrastructure to cause significant system failures, strategic leadership has a key role to play in aiding the process of making urgent choices about the appropriate level and type of investment required. Mobilisation of stakeholders etc. opens up the possibility of (i) new types of services being developed and (ii) changing user expectations.

Farming and allotment communities

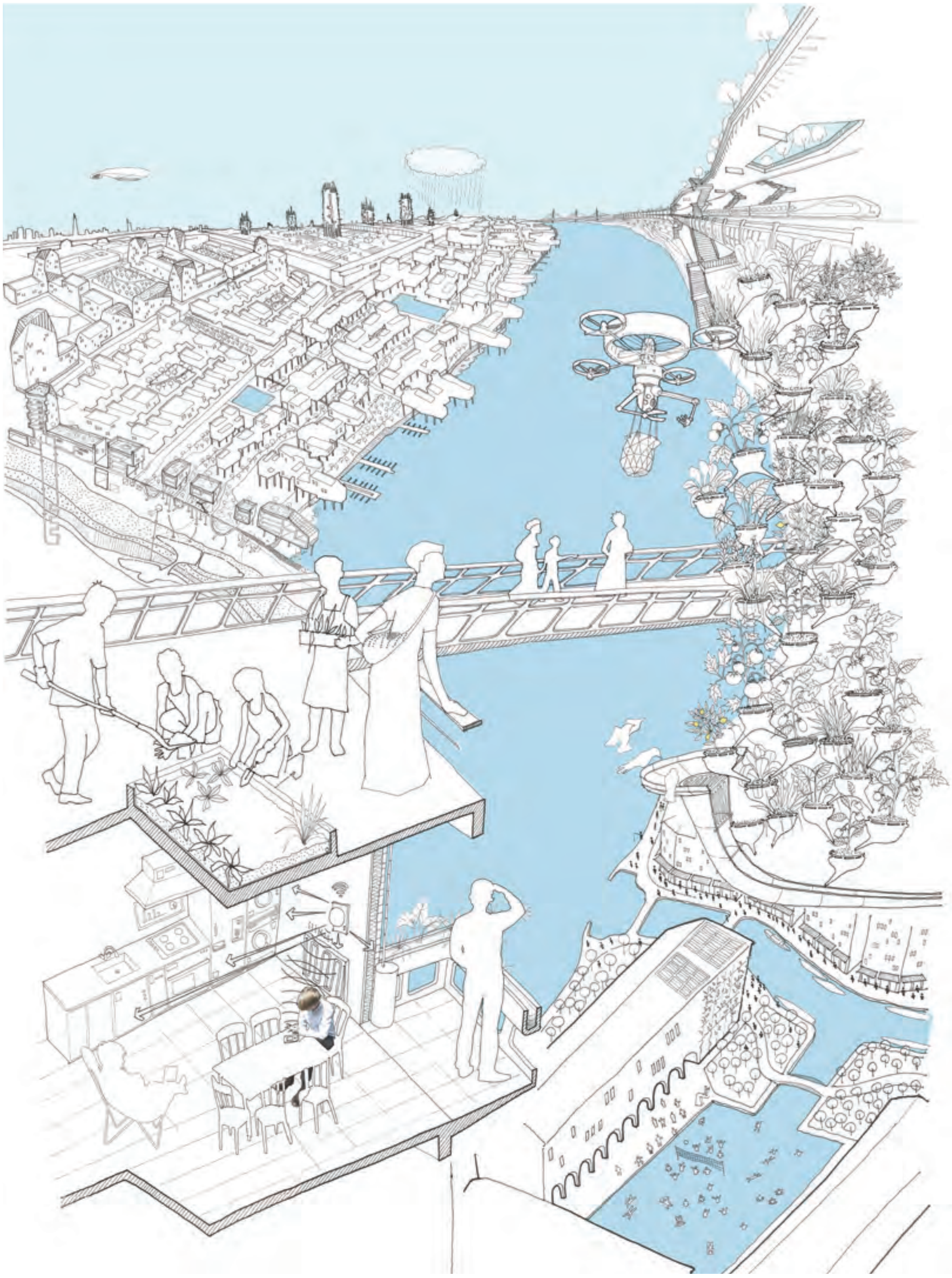


Productive landscape and community housing

4. Eight Underpinning Challenges: Research Status & Needs

If future visions such as those outlined in Section 3 are to be realised, a number of challenges need to be tackled. Below, eight such challenges are identified. In each case, together with a summary of its basic nature, the importance of addressing it successfully and some of the emerging priorities and opportunities, as well as a selection of current/recent research & innovation initiatives, are highlighted. So too are some key questions that remain to be addressed by such initiatives.

It is important to note that – as a result of the many linkages and interactions that exist across different spheres of urban research, development and innovation – the following challenges are not specific to individual visions but may underpin a number of them. Correspondingly, measures designed to address specific water-related issues in the cities of the future may span several of the challenges discussed.



Water Quantity/Quality for Life, Health & Leisure

Nature of the Challenge: This challenge embraces the most vital water needs of urban communities now and in the future, in terms of both water quantity and quality. It is vital to remember that, until the introduction of piped water supplies in the 20th century, human dwellings mainly developed within short walking distance of freshwater sources (rivers, springs, wells, rainfall capture surfaces etc.) that could be harnessed for basic drinking water, cooking and washing purposes. While these sources still exist in most cities, they may be contaminated (accidentally or maliciously) or insufficient to keep pace with 21st century urban population densities.

Importance, Priorities, Opportunities:

- Water represents by far the largest mass and volume moved in and out of cities every day. Each person in UK cities has a local water footprint that includes $60m^3$ of drinking water per year (Thames Water 2015) and production of about the same amount of wastewater (British Water 2009). The question is: if these needs are to become sourced more locally in future, how will cities and catchments cope?

- Until the introduction of the flush toilet, most human waste was conveyed to land, cesspits or drainage ditches/watercourses within walking distance of dwellings – posing a waterborne disease risk via potential contamination of a city's surface and groundwater sources used to supply drinking water. Illness and death from typhoid, cholera and dysentery still pose a major health hazard in cities lacking adequate sanitation. Even today, nearly 2000 children under five are estimated to die every day due to poor water, sanitation or hygiene (Unicef 2013). There is also a risk of the spread of antimicrobial resistant genes through groundwater.

- Across the globe, rapid urbanisation in low-income countries have spurred the development of mega-cities. In particular, water and sanitation in 'peri-urban' areas (i.e. areas located between suburbs and countryside) associated with unplanned city growth pose a huge challenge for water supply, drainage and waste disposal in terms of quantity, quality and safeguarding health; in such cases, adoption of more waterless and 'network-light' decentralised solutions could yield benefits.

- Research has shown that consumption habits are not static, but are a consequence of dynamic social practices embedded in social, cultural and material conditions (Medd and Shove 2005; Pullinger *et al*. 2013; Sharp 2006). Routines such as washing, heating, cooling and showering can be shaped, reinforced or challenged both by systems of provision and by the infrastructure incorporated into the built environment, with further work needed to understand the interactions between energy, water and carbon.

Current/Recent Research – Some Examples:

- **Sustainable Practices Research Group** – this consortium aimed to enhance, from a social science perspective, understanding of how habits in areas of everyday consumption form, reproduce and may be changed. (Supported by ESRC)

- **Risks and Responses to Urban Futures** – this project is exploring the intersections between ecosystem services and poverty in peri-urban areas of India, and the implications for urban development. (Supported by NERC)

- **Changes in Urbanisation and its Effects on Water Quantity and Quality from Local to Regional Scale** – this project aims to advance understanding of urbanisation's fine-scale impacts on water resources and pollution. (A NERC CEH initiative)

- **Clean Water for All** – this UK/US initiative aims to improve understanding of urban water use and flood risk management in the context of ensuring sustainability and resilience in water engineering. (Supported by EPSRC and the US National Science Foundation)

- **Safe and SuRe: Towards a New Paradigm for Urban Water Management** – this university fellowship aims to develop a new approach to water management in UK cities that delivers not only safety but also sustainability and resilience. (Supported by EPSRC)

- **Joint Programme Initiative, Water** – under the banner 'Water Challenges for a Changing World', this focuses on water and hydrological science in the context of the need to ensure water's availability in sufficient quantities and at adequate quality. (Supported by the EU and 19 national partners)

- **PREPARED: Enabling Change** – this collaboration worked with urban utilities in Europe and worldwide to develop advanced strategies to meet anticipated challenges in water supply and sanitation brought about by climate change. (Supported by the EU)

Kallang River Bishan Park, Singapore, courtesy of National Parks Board, Singapore

Key Questions & Research Gaps:

- How will climate change affect waterborne disease vectors in cities (e.g. will reintroduction of wetlands and marshy areas drained in the 1900s require action to reduce insect vectors)?
- What is the significance of urban diffuse pollution sources, in terms of their impact on sediments in surface waters?
- What impacts do urban water pollution and the potential passage of invasive species have on protected sites?
- How can green infrastructure be used to manage surface water and urban water pollution, while providing biodiversity and access to greenspace?
- What are the water quantity and quality implications of growing food in the city under different systems?
- How can decision-making processes and regulation be changed to encourage development of multi-functional places?
- Where, why and when do communities work together to manage urban watercourses – and what is needed for aspects of this 'formula' to be reproduced elsewhere?

End-user & City-dweller Behaviour/Demand

Nature of the Challenge: Using water more efficiently and, if possible, cutting overall demand are key goals for cities of the future, offering important benefits from both an environmental and an economic perspective. This is particularly the case in view of anticipated strains on water supplies resulting from rising populations and climate change.

Importance, Priorities, Opportunities:

- Encouraging uptake of water-efficient technologies and an increase in water-efficient lifestyles and behaviour, among domestic and other users, has a crucial role to play not just in cities but across society. Currently, water-efficient technologies are not widespread, nor are they expected to become so (Chappels and Medd 2008). If water efficiency is to become the norm, barriers and deterrents to take-up need to be better understood.

- Whether people are buying a newly built home or live in an older property, they have a level of choice whether to install and use water-efficient technologies. Waterwise's 'House of the Future' project is already examining social, technological and financial barriers, while a recent Waterwise/UKWRIP workshop highlighted the importance of tackling social and behavioural issues, especially in terms of how these interact with financial and technological barriers, and how they might be addressed through marketing, demonstration and awareness-raising initiatives.

- The Patterns of Water Consumption project (see below) has argued that interventions using tariffs, technology or information to influence behaviour are based on an overly simple model of how people behave. It sets out an alternative view that targeting consumers effectively means focusing on things they want to use water for (e.g. laundry, gardening), rather than the total quantity of water they use. For example, showering more than once a day mostly occurs among young people (Browne *et al*. 2013), so working with that specific group to examine whether, how and when the practice might be influenced could offer a productive way forward.

- A parallel set of social issues relate to flood preparedness and resilience. Householders and businesses in places vulnerable to flooding can take a series of actions to minimise damage and distress if and when a flood occurs (e.g. registering for information, having a flood plan, modifying aspects of their building). To date, however, actions tend to be most developed in locations that have flooded recently, raising questions about how wider awareness regarding flood risk and preparatory actions can be achieved in vulnerable locations where flooding has not occurred in recent years (Butler and Pidgeon 2011).

Current/Recent Research – Some Examples:

- **Environmental Assessment of Domestic Laundering** – this project has assessed domestic laundry practices with a view to highlighting how changes that result in health, economic and environmental benefits can be achieved. (Supported by EPSRC)

- **Greywater** – this initiative aimed to develop an effective greywater treatment appliance that uses a specially formulated, environmentally benign sterilant solution. (Supported by Innovate UK)

- **Patterns of Water Consumption** – this project has explored everyday domestic practices that use water and the diverse patterns that those practices can take, through a survey of 1800 people. (Supported by ESRC).

- **Urban Big Data Centre** – this unique research resource promotes the use of innovative methods and complex urban data to address challenges facing cities worldwide. (Supported by ESRC)

- **The Impact of Price and Information on Water Consumption** – this project is evaluating how consumer behaviour is changing in response to a Universal Metering Programme launched by Southern Water. (Supported by ESRC)

Action for the River Kennet (ARK)

Key Questions & Research Gaps:

- What is needed to overcome cultural, social and economic barriers to using less water? How can people be encouraged to change their lifestyles and behaviour, and how can households be encouraged to install and use water-efficient and energy-efficient technologies?
- How can regulatory bodies, urban planners, industry and other key influencers be encouraged to develop and promote water-efficient behaviour, policies, technologies and blue-green infrastructure?
- How does the property marketing and rental sector view the value of, and other issues relating to, properties that have a greater proportion of water-efficient technologies, such as rainwater harvesting and water reuse?
- Could research looking at the relationship between water use and other services/utilities (e.g. electricity, gas) highlight interesting interrelationships and enable water consumption to be inferred from electricity metering, for example?
- Could research aid the development of new low-energy or zero-energy solutions for pumping water collected by rainwater harvesting installations?
- When/how/should the public be engaged in broader decisions about society's water choices (e.g. choosing between reducing water demand and the environmental damage and financial cost of new investment)?

Infrastructure: Above Ground

Nature of the Challenge: With respect to infrastructure, is small beautiful or is it a case of big-is-best? Is centralised better than decentralised? Debate has long raged, along with claim and counter-claim, about the most appropriate scale for the provision of water services in cities. Above-ground infrastructure is a key case in point. (See next challenge for below-ground infrastructure.)

Importance, Priorities, Opportunities:

- Reaching robust conclusions about how above-ground water-related infrastructure can best meet diverse (and sometimes potentially conflicting) economic, environmental and other requirements is vital to the success of the cities of the future.
- Currently, cities have very centralised water systems that operate on a 'command and control' basis. The latest thinking, however, argues that local or semi-localised systems are the way forward, offering a range of practical, economic and environmental benefits (Zhang *et al*. 2009).
- In the UK, only tentative steps have been made towards developing and implementing more decentralised approaches to water service provision. Examples include SuDS, in addition to rainwater and greywater recycling. Guidance and regulation around these measures is disparate and inconsistent, and the applications are far from widespread. However, they could considerably reduce reliance on water from far-distant sources and help deliver water security in times of drought, plus give greater resilience generally. Local water storage/treatment might yield similar benefits but requires a new conception of water and wastewater infrastructures; marrying this idea with roof gardens, urban farms and other urban green infrastructure systems could enable implementation of improved city water systems.
- Traditionally, infrastructure has been left to the water industry. Although overall they have done a good job to date, developing new solutions for the future requires the engagement of the wider water sector, key stakeholders and customers.

Current/Recent Research – Some Examples:

- **Pennine Water Group (PWG): Urban Water Systems for a Changing World** – this initiative focuses on sustainable integrated systems, water-sensitive urban design and the development of new technologies. (Supported by EPSRC)
- **Ciria Scoping Report, Ideas Booklet and Advice Note** – construction industry research & information association Ciria has identified further work needed in the field of water-sensitive urban design.
- **TRUST: TRansitions to the Urban Water Services of Tomorrow** – this multinational project is researching innovations and tools to create a more sustainable water future, with results to be tested in pilot cities/regions. (Supported by the EU)
- **City Blueprints Action Group** – aiming to improve the implementation capacities of cities and regions, this initiative has set out to establish a network of European cities that share best practice in the sphere of urban water-cycle services. (Supported by the EU)
- **Liveable Cities** – this project is developing a City Design Framework that will measure how cities operate and perform in terms of their people, environment and governance, taking account of wellbeing and resource security. (Supported by EPSRC)
- **Land of the MUSCos** – this project has researched and promoted the establishment of Multi-Utility Service Companies (MUSCos) that offer a single point of service to multiple utilities and profit from service delivery rather than product sales. (Supported by EPSRC)

Image courtesy of XP Solutions Software Ltd

Key Questions & Research Gaps:

- What are the costs and benefits of different scales of provision, especially in terms of possible economies of scale, system performance and reliability, and what changes in behaviour and attitude are needed if services are localised?
- What should a 'blue-green-grey' integrated water management strategy encompass for new greenfield development? What new stakeholder relationships and engineering/other processes are needed, in terms of urban socio-technical systems, governance structures etc.?
- How can water be valued and priced in order to find ways to pay for new or upgraded water systems, while factoring-in risk? Answering this question will inform 'willingness to pay' discussions, as will better understanding of the impacts of extreme weather events.
- Is it possible to develop cost-effective solutions that can reduce loads on infrastructure systems resulting from population and environmental pressures?
- Could local sourcing of water and the matching of water quality to water use transform the water supply landscape, yielding benefits in terms of the amount of energy and other resources used in the treatment and transportation of water?
- Can business models for the delivery of non-conventional solutions be developed further (and linked to the new retail separation in the industry introduced by the 2014 Water Act[3])?
- What are the downstream effects of changing the urban water infrastructure on the surrounding rural and agricultural landscape, for example, flooding or polluting of grassland or arable areas?

[3] **http://www.legislation.gov.uk/ukpga/2014/21/contents/enacted**

Infrastructure: Below Ground

Nature of the Challenge: Away from reservoirs and treatment works, infrastructure systems are typically buried underground. This means that, as well as being part of the built environment, they interface closely and (to an extent) exist symbiotically with the natural environment. In particular, they are subject to stresses associated with a range of mechanical, chemical and environmental phenomena, which also accelerate the ageing processes affecting the materials and components that buried infrastructure systems consist of. All of these factors can adversely impact system performance.

Importance, Priorities, Opportunities:

- Water and wastewater infrastructure systems are sophisticated and complex, interfacing with the public at the point of use. In addition, many dependencies and interdependencies exist with other infrastructure systems and other rural or urban systems too. Ensuring that below-ground infrastructure is fit for purpose, now and into the future, is therefore not only of key importance in terms of continuity of supply and economic/environmental performance; it is also an extremely complicated issue. Dependencies and interdependencies provide not only risks, but also opportunities that novel business models might be able to exploit.
- A major challenge, especially relevant to cities, revolves around congestion and its mitigation. Water and wastewater infrastructure systems, which are commonly buried beneath roads, can significantly affect this issue. Primarily, traffic congestion is exacerbated by streetworks – and to a far greater degree when trenching is relied on, as opposed to minimum-dig or no-dig methods. Furthermore, all three of the interdependent infrastructures involved (buried utility infrastructure, transport/road infrastructure, and the ground/geotechnical infrastructure that supports both of these) are affected and often damaged when physical interventions are applied to buried utility infrastructure systems.
- ‘Trenchless technologies’ have great potential but are greatly underexploited, partly due to the business models and business cases that are currently applied to streetworks. If the value of using these technologies could be captured and alignment achieved between ‘who pays?’ and ‘who benefits?’, the overall benefits could be substantial.
- Overall, use of underground space is potentially a key enabler of more sustainable and resilient cities. Although shallow depths are already often heavily congested with a spaghetti of utility pipes and cables, enormous scope exists to utilise lower depths in a range of innovative, imaginative and productive ways.

Current/Recent Research – Some Examples:

- **International Centre for Infrastructure Futures (ICIF)** – this national-scale initiative aims to enable better exploitation of technical and market opportunities emerging from increased interdependence of infrastructure systems. (Supported by EPSRC & ESRC)
- **i-BUILD: Infrastructure BUsiness models, valuation and Innovation for Local Delivery** – at the neighbourhood, town and city scale, this collaboration is analysing innovative business models around infrastructure interdependencies. (Supported by EPSRC & ESRC)
- **Smart Infrastructure: Wireless Sensor Network System for Condition Assessment and Monitoring of Infrastructure** – this collaboration aimed to develop low-cost sensing for the monitoring of ageing public infrastructure. (Supported by EPSRC)
- **Mapping the Underworld: Multi-sensor Device Creation, Assessment, Protocols** – this international collaboration aimed to create an innovative device combining radar, acoustics etc. to locate underground utilities. (Supported by EPSRC)
- **Assessing the Underworld: An Integrated Performance Model of City Infrastructures** – this major international project aims to use geophysical sensors to determine the condition of buried water pipes without the need to excavate them. (Supported by EPSRC)

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Key Questions & Research Gaps:

- How can future functional performance (in terms of leakage, pollution etc.) and asset life be determined swiftly, accurately and, ideally, remotely through sensors, remote sensing and condition/deterioration models, in order to deliver commercial, social and environmental benefits?

- What role could monitoring and smart operation using sensors and sensor systems play in optimising system operation and maintenance?

- How can detection, location and mapping of buried assets be improved, along with the creation and maintenance of accurate, up-to-date records of buried infrastructure? How can asset condition/performance data and interactions with other infrastructure systems be added to this core data?

- How can greater intelligence be gathered to inform streetworks?

- How can greater use of, and greater innovation in the field of, multi-utility conduits and tunnels be encouraged in order to yield multiple benefits (e.g. when combined with sensors, maintenance regimes could be transformed, performance enhanced etc.)?

- Could the huge range of ‘trenchless technologies’ be more widely exploited?

City Groundwater Management

Nature of the Challenge: Although closely related to the issue of below-ground infrastructure, groundwater – and specifically its function, governance and sustainable management in an urban context – demands special consideration. Any city-centric model of water issues has to take groundwater into account and recognise that water resources are supplied from a wider catchment area extending beyond the city's administrative boundary, with flows into and out of the city hub requiring consideration.

Importance, Priorities, Opportunities:

- Groundwater is intimately linked to people (water supply, amenity), environment (ecology, biodiversity, hazards) and industry (energy, construction, agriculture, infrastructure). According to the ecosystem services philosophy, it offers provisioning (water supply, heat), regulating (water quality, heat), cultural (amenity) and platform (construction, drainage) services (Millennium Ecosystem Assessment 2005). There may be competition between agricultural and urban environments for the use of ground water.
- In cities, groundwater interests extend to: water supply; ecological and amenity value of groundwater-dependent rivers and wetlands; and provision of geothermal ground-source heating and cooling. Groundwater supports over half of all public water supply in SE England (Environment Agency, undated) and accounts for around 60% flow of the River Thames in London (NERC 2008).
- From a city perspective, groundwater-related concerns include: flooding (acute flooding during extreme rainfall events, plus chronic flooding as groundwater levels rise beneath cities in response to reduced groundwater abstraction); groundwater ingress into subsurface infrastructure and services (e.g. posing problems for sewers, as well as for construction projects associated with shallow groundwater and saturated land); and deterioration of water quality due to pollution.
- Groundwater influences the regulation of subsurface processes and services in cities; for example, the capacity for SuDS, managed aquifer recharge, dilution of wastewater, dissipation of contaminants, regulation of the urban heat island, and subsurface building and infrastructure design.
- Many cities are built on geology that includes permeable strata which may be used as a resource of water for drinking or for industrial, irrigation or cooling/heating purposes. In many cases, urban industrialisation and human wastewater pollution may have reduced groundwater quality to levels where it is uneconomic to use as a high-quality resource.
- Rainfall falling on hard surfaces in cities is mainly drained to wastewater plants and storm overflows, reducing the natural recharge of groundwater with potentially higher-quality water. London is one of the few cities where a Managed Aquifer Recharge scheme (NLARS – North London Aquifer Recharge and Storage) has been constructed. At present, recharge is provided from surplus fully treated drinking water available during winter periods.

Current/Recent Research – Some Examples:

- **BGS Groundwater Programme** – this NERC British Geological Survey (BGS) programme addresses issues related to: the sustainability of water resources and quality; the impacts of environmental change on the water cycle; natural hazards; and groundwater & human health.
- **Sub-Urban** – this European network involves geological surveys, cities and research partners working together to improve the management of the ground beneath cities. (Supported by the EU)
- **Accessing Subsurface Knowledge** – this data and knowledge exchange network aims to aid understanding of ground conditions and so help delivery of successful construction and regeneration projects. (Developed by BGS and Glasgow City Council)
- **Provision of Subsurface Information Relevant to SuDS and Infiltration** – BGS is actively engaged in a range of research related to SuDS, aimed at maximising the benefits of these systems and understanding/mitigating their impacts.

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Key Questions & Research Gaps:

- How can the need for city-scale monitoring and assessment of groundwater best be met? Currently, very few cities have dedicated groundwater monitoring networks and few UK studies have looked at shallow urban aquifers. Can a more robust methodology for urban groundwater planning be developed (current guidance being based on 1970s research)?

- Can the full potential of managed aquifer recharge/storage and the source, quantity and quality of potential recharge water be identified? Can priority UK aquifers be assessed with respect to their potential impact on urban areas, the wider water cycle and the provision of services for cities (e.g. water resources, wastewater reuse, heating, cooling)?

- What scope is there for managing urban aquifers and for the creative use of polluted aquifers/recharge?

- Can understanding be improved of the scientific, regulatory and operational risks involved in using aquifers identified as potential locations for managed aquifer recharge, in order to remove a potential brake on implementation in the UK?

- Can better understanding be developed about urban recharge processes and shallow urban aquifers, in terms of their ability to reduce the effects of hydrological extremes? Can better understanding also be developed about the effect of city-wide SuDS implementation? Can urban water ecosystem services be improved?

- Could a city sustain itself with zero demand on the external water cycle (in terms of both catchment and groundwater) by harnessing rainfall and recycling water within the city?

- Can critical thinking be applied to the topic of effective governance in the face of growing natural and manmade threats to water infrastructure? For example, what governance structures, institutional arrangements and water policies are most effective in achieving sustainable and resilient management of groundwater in UK cities? How effective or vulnerable are water demand management strategies within UK cities?

Risk & Resilience to Extreme Events

Nature of the Challenge: Cities have been built in a wide range of climatic areas, from deserts to monsoon regions. Understanding the risks they face in terms of extreme weather events and building resilience against these is a key challenge, especially in view of the evidence that climate change may alter both annual rainfall patterns and the frequency and intensity of extreme rainfall events. Evidence also exists that cities may alter local climates by generating a heat island effect and disturbing rainfall patterns. In addition to natural hazards, wider threats to city infrastructure may result from changes in policies and governance, economic crisis, war and acts of terrorism.

Importance, Priorities, Opportunities:

- The UK Met Office defines extreme or violent rainfall in the UK as greater than 50mm per hour (equivalent to a typical month's total rainfall) (Met Office 2012). City drainage systems of the future are likely to have to withstand and manage the impacts of such events more frequently. Recent research on Southern Britain conducted by the Met Office and Newcastle University has indicated that, according to current climate change predictions, rainfall events with an intensity of over 29mm per hour will become five times more common by 2100. Such intensities are often associated with flash-flooding (Kendon *et al*. 2014).
- Current rainfall events and drainage designs in the city of Singapore may provide an indication of the future needs of cities located in rainfall regions presently categorised as 'moderate': 60mm of rainfall per hour has a 2 year return period, whereas 150mm of rainfall per hour has a 100 year return period (Public Utilities Board, Singapore 2011).
- Although understanding of how water impacts on infrastructure has improved, there is still a significant amount of work to do in fields such as climate change, extreme weather events, water scarcity and critical interdependencies between different infrastructure networks (e.g. electrical networks provide power for water infrastructure systems).

Current/Recent Research – Some Examples:

- **BlueGreenCities** – using Newcastle as a demonstration city, this project aims to develop new strategies for managing urban flood risk as part of wider, integrated urban planning intended to achieve environmental enhancement and urban renewal. (Supported by EPSRC)
- **Before the Flood** – this project explored the scope to build resilience among hard-to-reach urban communities at risk of flooding by staging performance events and developing narrative-based audio resources, for example. (Supported by AHRC)
- **CONVEX** – with the aim of helping to improve prediction of changes in extreme rainfall, this initiative is investigating improvements in the simulation of extreme rainfall by regional climate models. (Supported by NERC)
- **Organisational Operational Response and Strategic Decision Making for Long Term Flood Preparedness in Urban Areas** – this initiative is developing a model that can help organisations make themselves more resilient to flooding. (Supported by EPSRC)
- **Flooding from Intense Rainfall** – this programme aims to reduce the risks of damage and loss of life due to surface water flooding and flash-floods by better understanding processes that contribute to flooding associated with high-intensity rainfall. (Supported by NERC)
- **UK Droughts and Water Scarcity** – this programme aims to aid decision-making relating to droughts and water scarcity by examining the interrelationships between their drivers and impacts. (Supported by NERC, with ESRC, BBSRC, AHRC and EPSRC)
- **Flood MEMORY: Multi-Event Monitoring Of Risk and recoverY** – this project is looking at the most critical flood scenarios caused by sequences/clusters of extreme events striking vulnerable flood defences, urban areas, communities and businesses. (Supported by EPSRC)
- **National Hydrological Monitoring Programme** – this programme provides an authoritative voice on hydrological conditions and trends throughout the UK. (Jointly undertaken by CEH and BGS)
- **RAMSES: Reconciling Adaptation, Mitigation and Sustainable development for citiES** – the main aim of this project is to deliver quantified evidence of climate change impacts and the costs/benefits of a range of adaptation measures, focusing on cities. (Supported by the EU)
- **SESAME** – this project is developing tools that encourage small and medium-sized businesses to discover ways of becoming more resilient to floods and to appreciate how much better off they will be once they have adapted to the ongoing risk. (Supported by EPSRC)

- **Storm Risk Mitigation** – comprising three inter-connected projects, this programme has aimed to improve short-term and longer-term forecasting of storms and their impacts on catchments and coasts. (Supported by NERC)

- **Threats to Infrastructures: Consolidation, Collaboration and Future Orientation** – this research involves constructing and analysing 'timelines' of infrastructure protection policy and of mass population response to see how and why policy changes. (Supported by ESRC)

- **STEPS (Social, Technological and Environmental Pathways to Sustainability) Centre** – in fields as such food/agriculture, health/disease and water/sanitation, this centre looks at how pathways to sustainability can be built in today's complex world. (Supported by ESRC)

Key Questions & Research Gaps:

- How can research on extreme events (e.g. regarding interventions and resilience with respect to droughts and flooding) be integrated with whole-system understanding?

- What further preparations could help to combat the expected increase in the frequency and magnitude of extreme climatic events, beyond 'grey engineering' approaches? Research is needed on: resilience-building (i.e. emergency planning); innovative warning systems; clean-up; costs (i.e. who pays?); infrastructure protection planning/policies; and user behaviour.

- What impact will climate change have on water in cities, as a result of rainfall, river, groundwater and sewer flooding, and taking account of preceding conditions?

- How can properly integrated water-cycle models that improve resilience best be developed?

- What rainfall intensity scenarios should future cities be considering for the period 2050-2100?

- What innovations in governance systems and structures are likely to enable government and industry to respond effectively to predicted and unforeseen environmental hazards?

- What mitigation strategies should be in place in case of major malicious disruption to water supplies or the contamination of drinking water (including the role of communications and raising public awareness on required actions to minimise negative impacts)?

Environment & Ecosystems

Nature of the Challenge: Cities of the future will need to consider the wider environment and how the goods and services they depend on are secured. Population growth and climate-driven events are two key factors that could result in greater reliance on local provision. In such a scenario, local ecosystems not only need to be protected – they could also help to meet demand by providing a wide range of goods and services.

Importance, Priorities, Opportunities:

- Urban ecosystems are one of eight categorised habitat types identified in the UK National Ecosystem Assessment (2011). The key goods, services and benefits these ecosystems provide are: access to good-quality urban green and blue space, facilitation of positive mental health and childhood development as well as physical health; promotion of community cohesion, neighbourhood development and social/environmental citizenship, through the use of greenspace; improved water quality and quantity, both of which are adversely affected by impermeable urban land.
- Systematic collection of data on the natural environment in towns and cities is poor. For example, while domestic gardens cover 22-27% total urban area in many cities (RHS 2011), little is known about their condition; they are also at risk from infilling, non-permeable surfacing, low biodiversity and reduction in size.
- Huge opportunities exist, to seek nature-based solutions that improve and enhance ecosystem goods and services, including:
  - o Multi-functional use of space to improve access to greenspace, to reduce heat island effects, to minimise flood risks and to reduce pollution.
  - o Increased planting of trees and creation of 'green bridges'.
  - o Leaving rivers in a more natural state to enhance local flood mitigation and flood storage capacity, while reducing downstream flooding, as a cost-effective alternative to traditional engineering.
  - o Meeting community-led demand for cultivation by converting non-permeable surfaces and by provision of spaces in parks and areas of non-contaminated brownfield land.
  - o Creating, maintaining and championing good quality, accessible blue-green spaces, parks and woodlands in high population density areas, and encouraging better use of gardens.
  - o Sustainable use of above-ground SuDS in cities.
  - o Use of storm water and groundwater, including greater use of bio-retention and rain gardens.

Current/Recent Research – Some Examples:

- **Fragments, Functions, Flows and Urban Ecosystem Services (F^{3}UES)** – this collaboration is looking at how the biodiversity of towns and cities contributes to human wellbeing through delivery of ecosystem services. (Supported by NERC)
- **Urban River Corridors and Sustainable Agendas (URSULA)** – this project investigated the sustainable development of urban river corridors. (Supported by EPSRC)
- **Hydrological Extremes and Feedbacks in the Changing Water Cycle** – this project integrated climate science and hydrological science to take impact modelling beyond the previous state of the art. (Supported by NERC)
- **The Mersey Forest** – involving and supported by multiple partners including Natural England and Liverpool City Council, this growing network of woodlands and greenspaces across Cheshire and Merseyside has been creating 'woodlands on your doorstep' for 20 years.
- **FAAN: focusing on Alternative Agri-Food Networks (AAFNs)** – this collaboration investigated a range of networks (community gardens, farmers' markets etc.) characterised by economic relations going beyond market relations. (Supported by the EU)

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Key Questions & Research Gaps:

- What are the environmental implications of the use of above-ground SuDS in cities and the use of storm water and groundwater, including greater use of bio-retention and rain gardens?
- What would be a good ecosystem management approach to rivers, surface waters, flood management and sustainable drainage in cities?
- How can long-term monitoring be best applied to the development of urban wetland ecosystems, in terms of their benefits (e.g. biodiversity, amenity), drawbacks (e.g. insects, rats, disease vectors) and implications for operational management?
- What challenges would urban farming (e.g. aquaculture, use of roof space and walls) pose for water and ecosystem management in future cities?
- How can our primitive understanding of the interactions between human and ecological functions in cities be improved?
- How can the increase in ecological planning be reflected in formal urban planning systems?
- How can an ecosystems approach be best applied to urban water management and how can understanding of the impacts of key catchment pressures be improved?
- What influence will climate change and changing demographics have on growing demand for water (e.g. for showers, gardens) and potential increases in food production in future cities?
- What are the health, social and environmental benefits of creating or enhancing blue space?
- As urban problems may stem from catchment issues in rural areas and vice versa, can integrated rural/urban catchment management be developed effectively?
- How might discharge permits relate more directly to chemical water quality, ecosystems and 'good ecological status' under the Water Framework Directive?

Cross-cutting Issues & Whole-system Approaches

Nature of the Challenge: As this paper demonstrates, very few issues relating to water management for cities can be separated from drivers and impacts originating well beyond the water industry and water science. Optimising the relationship between water and the cities of the future will therefore require a focus not just on a range of cross-cutting issues but also on 'whole-system approaches' that integrate different parts of socio-economic systems and recognise the impact that every part of a system will have on every other part.

Importance, Priorities, Opportunities:

- Currently, water management in cities is hampered by the disconnect between different governing organisations: local authorities, regulators, and water, waste and energy suppliers. In view of the many interfaces that exist with other systems (political, infrastructural, community, economic, behavioural etc.), system linkages need to be understood and the complexity of urban systems needs to be recognised.
- The UK's Natural Capital Committee has highlighted concerns at the failure to recognise the value of natural assets when considering urban/infrastructure development (Natural Capital Committee 2015). A more holistic and integrated planning approach would need to consider the availability of (and sustainable management for the provision of): water (including water quality); energy; food; natural flood protection; waste management; and risks/opportunities in the sphere of health & wellbeing.
- When ensuring the viability of any major development with regard to sustainable living, the starting point needs to be a comprehensive understanding both of the natural assets and of the goods and services potentially available within the area (e.g. a catchment) that will accommodate that development. The UK National Ecosystem Assessment 2011, which followed the 2005 Millennium Ecosystem Assessment, provided the first analysis of the UK's natural environment in terms of the overall benefits it provides for society and for continuing economic prosperity.
- Over the next 50 years, there will be many opportunities to make use of rapidly developing sensor, data collection/analysis and computer modelling capabilities. Key topics with the potential to play a pivotal role in cities of the future include: ICT for smart water and energy devices; smart networks; and home water/energy control hubs.

Current/Recent Research – Some Examples:

- **REFIT: Personalised Retrofit Decision Support for UK Homes Using Smart Home Technology** – with a focus on energy, this project aims to facilitate uptake of retrofit measures through a holistic approach to providing consumers with tailored advice. (Supported by EPSRC)
- **Running the River Thames: London, Stakeholders and the Environmental Governance of the Thames, 1960-2010** – this project provided a historical account of changing modes of public participation and political legitimacy. (Supported by ESRC)
- **ReVISIONS: Regional Visions of Integrated Sustainable Infrastructure Optimised for NeighbourhoodS** – this project set out to help public agencies and private companies plan in a more co-ordinated and integrated way. (Supported by EPSRC)
- **Future Cities Catapult** – focused on urban innovation, this centre is exploring how cities can take a more joined-up approach to the way they plan and operate, in order to improve quality of life, strengthen their economy and protect the environment. (Supported by Innovate UK)
- **Risks and Responses to Urban Futures** – this project is exploring the intersections between ecosystem services and poverty in peri-urban areas of India, and the implications for urban development. (Supported by NERC)
- **'Smarter' Homes?: A Netnographic Exploration of Low Carbon Living** – this initiative is exploring experiences of occupants of low-carbon/energy-efficient housing to understand energy demand creation and how technology influences energy use. (Supported by ESRC)

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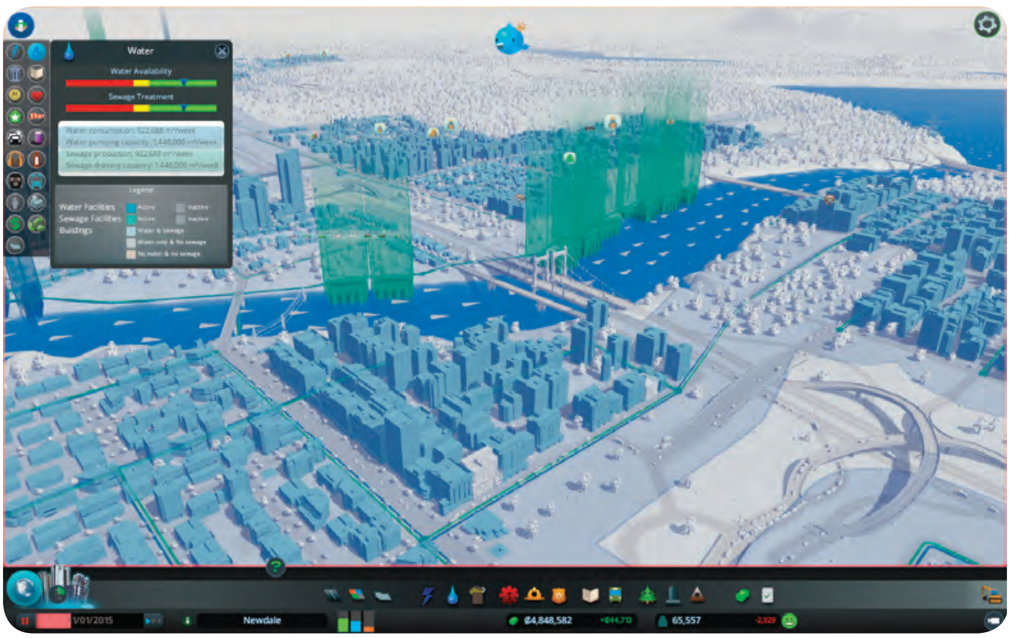
Key Questions & Research Gaps:

- How can optimal integrated approaches be developed that plan for urban development which is underpinned by assessments of local natural capital assets?
- How can important opportunities, supported by advances in technology, to improve the linkage between multi-scale, transdisciplinary, integrated models or simulators and basic measurements of small-scale processes be realised?
- What governance and regulatory models would work for a complex 'system of systems' for cities of the future?

5. Towards Tomorrow: City Simulators & Demonstrators

When exploring the opportunities and evaluating the risks associated with water and its role in the cities of the future, city simulators and demonstrators offer a potentially effective means not only of 'de-risking' innovative ideas but also of testing their interactions with non-water systems.

- **City Simulators:**
  - Although still at a very early stage of development and application, computer simulations using cities as 'living laboratories' and validated through experiments and demonstrators present one of the most exciting opportunities to improve the quality of urban living for all citizens.
  - City simulators could help to target research designed to deliver better city planning, by creating interactive models that incorporate infrastructure, ecosystems, planning and maintenance, resilience to extreme events, socio-economic service levels, and demand and pricing systems for water, food, energy and transport.
  - City simulator models need to embrace: individual human and community behaviours; individual building and city network scales; and operational timescales ranging from hours to decades.
  - A simulator could cover issues such as hydrology, engineered networks, water quality, heat balance, greenhouse gas footprint and ecosystem benefits, factoring-in issues such as groundwater, rainfall, in-city water mass balance and domestic/community-scale water use and reuse. This would enable testing and virtual engineering of innovative concepts, and the building of a picture of whole water-cycle management at domestic, city and catchment scale.
- **City Demonstrators:**
  - Community-scale city demonstrators could aid investigation of the life-cycles and interactions of innovative solutions to water, food, waste and energy management challenges in the urban communities of tomorrow.
  - Such demonstrators could, for example, focus on smart homes, smart networks, robotic repair technologies, urban agriculture, ecosystem and aquifer recharge, sustainable drainage, and floating cityscapes.
  - Severn Trent Water is currently planning a major urban water demonstrator within the city of Birmingham.
  - Innovate UK's **Future Cities** initiative will award funding to the UK city or urban area that delivers the best proposal for a large-scale 'future cities demonstrator' integrating multiple systems and addressing a range of challenges facing the cities of tomorrow.



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6. Conclusions & Next Steps

Envisioning cities of the future that are focused around different approaches to water management can help us understand how water as a system of systems can improve our quality of life. Setting out exemplar visions of the kind presented in this paper can also aid the process of identifying what research and other tools are needed to achieve them, or selected components of them. Developing and exploring such visions, then, adds real value to the debate about the future relationship between water and cities, and needs to be given due priority.

If these or similar visions are to become reality – especially in the context of increasing pressures on water and land, increased urbanisation and the effects of climate change – substantial research & innovation challenges need to be addressed successfully. Key topics include: the potential of blue-green infrastructure for flood resilience; community approaches to water management; the need for new governance and regulatory models; ecosystem approaches and integrated urban/rural catchment management; increased monitoring and sensors; managed aquifer recharge; the effects of urban agriculture and climate change on water quality; and the use of urban demonstrators and city simulators to test new technologies and approaches.

Next Steps

UKWRIP is keen to work further with the Foresight 'Future of Cities' project to identify the many water-related opportunities and challenges that UK cities will face in the future. In this document, we set out to highlight the issues that need to be addressed in order for cities in the UK and across the globe to be resilient, to be adaptable and to thrive.

To assist further discussion and deliberation, we offer four very broad recommendations relevant to the UK research, development & innovation communities, and which Foresight may wish to support:

1) Encourage the use, refinement and augmentation of the visions included in this publication, adapting them where needed, in order to engage with city authorities and help them develop their future city plans.

2) For each of the eight underpinning challenges described, note the gaps highlighted in this publication as a result of synthesising past research outputs, and encourage further review and assessment of existing and planned research to see how those gaps are being addressed.

3) Promote further engagement between relevant researchers and users of urban research in order to translate research outputs into targeted outputs for users (planners, policy-makers, businesses, community organisations etc.).

4) Support and inform the development of research & innovation opportunities through the UK Research Councils, Innovate UK and business partners (e.g. water utilities and consultancies) such as multi-disciplinary programmes, city simulators and city demonstrators, to address the challenges described.

Appendix 1

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UK Research Councils referred to in this paper:

AHRC: Arts and Humanities Research Council

BBSRC: Biotechnology and Biological Sciences Research Council

ESRC: Economic and Social Research Council

EPSRC: Engineering and Physical Sciences Research Council

NERC: Natural Environment Research Council

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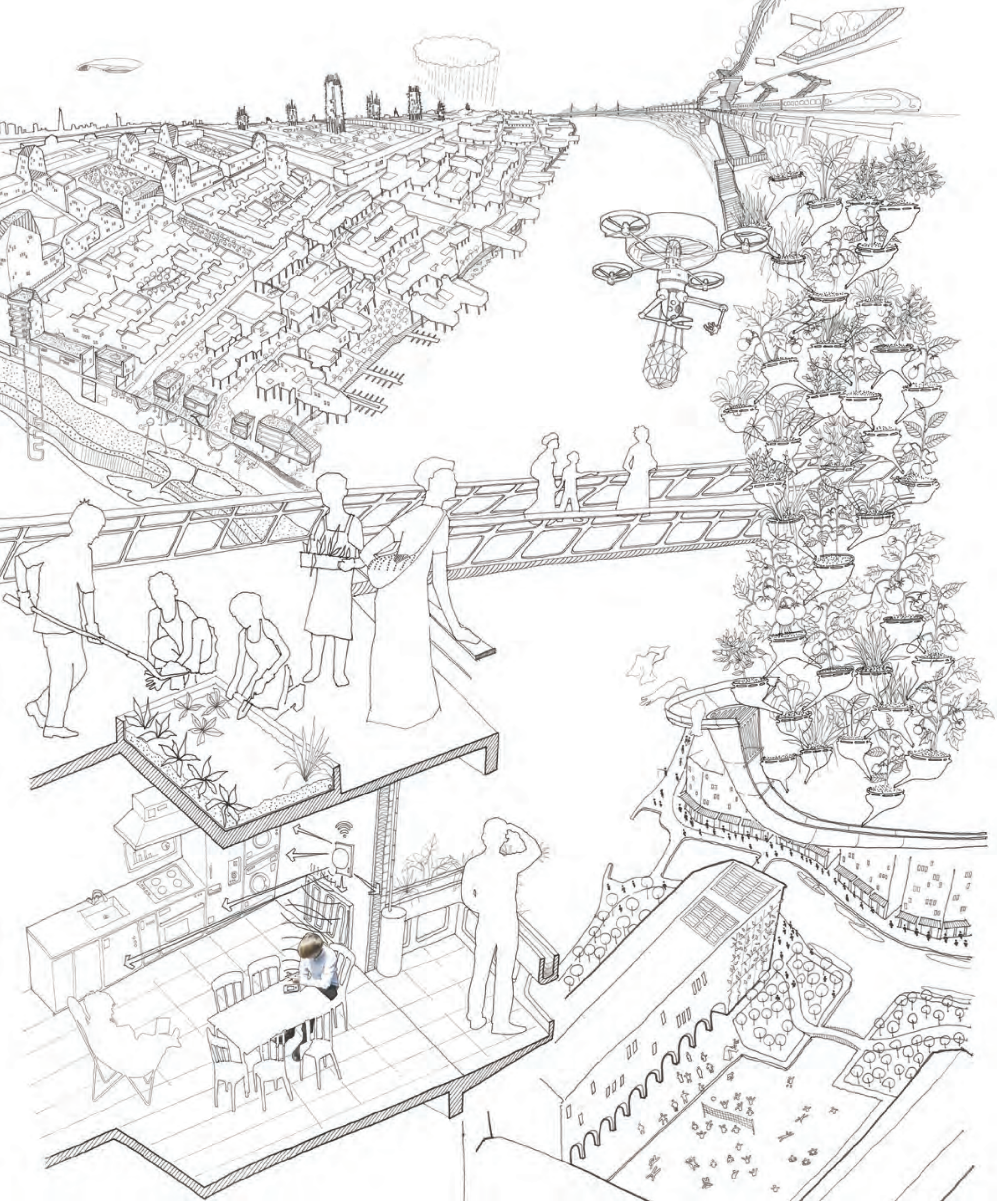

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