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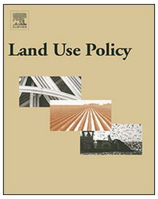

Accounting for groundwater in future city visions

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ABSTRACT

City planners, urban innovators and researchers are increasingly working on ‘future city’ initiatives to investigate the physical, social and political aspects of harmonized urban living. Despite this, sustainability principles and the importance of urban groundwater are lacking in future city visions. Using London as a case study, the importance of groundwater for cities is highlighted and a range of future city interventions may impact on groundwater are reviewed. Using data from water resource plans and city planning strategies, changes in the groundwater balance which may occur as a result of city interventions are calculated for two future city scenarios: a ‘strategic’ future informed by organisational policy and an ‘aspirational’ future guided by sustainability principles. For London, under a strategic future, preferential investment in industry-scale technologies such as wastewater treatment and groundwater storage would occur. Acknowledgement that behaviour change offers the potential for a faster rate of transformation than innovation technologies is ignored. The capacity of community-led action and smart-home technologies to deliver sustainable water use under an aspirational future is evident, with a measurable impact on urban groundwater. These methods may be used to inform city interventions that consider the social context in addition to environmental constraints and business drivers.

1. Introduction

As urban populations continue to dominate globally, city planners, urban innovators and researchers are increasingly working on joint initiatives to investigate the physical, technological, social and political aspects of harmonized urban living. The aim is to create cities which perform well, that are, prosperous, sustainable, resilient, and liveable. Whilst significant attention is given to smart city information technologies, data and innovation products, the broader city initiatives tend towards ‘future city’ concepts where knowledge dissemination, co-operation, policy reform and urban design run in parallel with big data and smart technologies (Rogers et al., 2012; Angelidou, 2015). Despite this broader approach to future city thinking John et al. (2015), in their review of 92 urban visions across 13 countries, found that sustainability principles were poorly covered and that no city fully integrated all of the defined sustainability principles (i.e. relating to built form; ecosystems services; resource consumption and production; social and cultural practice; governance, and; city-catchment systems) within their vision. In the context of a sustainable urban future, the vision may be defined as a desirable society, which provides permanent prosperity within biophysical constraints and in a manner that is fair and equitable now and in the future (Costanza, 2000). A city foresight exercise, undertaken by the UK Government Office for Science, aims to gather science evidence in support of policy decisions to inform the analysis, design and transformative actions needed to shape the UK’s urban future (GO-Science, 2016). Adopting a trans-disciplinary approach, the foresight exercise considers urban economies, metabolism, form, infrastructure, governance, and city living. At a time when sustainability principles need promoting in city visions, inclusion of urban metabolism is critical. Originally proposed by Wolman (1965) urban metabolism may be defined as the inflow and outflow transactions required to sustain city functions, or the production, consumption and disposal of resources (Huang and Hsu, 2003). In this way the biophysical demand to sustain urban society is evaluated. Linking urban metabolism concepts with future city programmes brings another dimension to urban performance metrics by making the connection between the city and its resource support area, commonly referred to as its hinterland (Lee et al., 2016). Here, there is an acknowledgment that, in terms of resource demand, the city cannot sustain itself using only materials within the city limits and additional resources must be imported; and it follows that the by-products, or waste, arising from city metabolism are also disposed of beyond the city boundary. Strongly aligned with urban metabolism principles is the ecosystem services approach adopted by UK National Ecosystem Assessment (2014) through the Natural Capital Asset Check. Here the ecosystem services (stocks and flows) provided by the natural environment within the city and its hinterland are

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Table 1
Anthropogenic interventions in the urban water cycle (recharge, through flow and discharge).

	Human intervention	Potential impact
Recharge		
Evaporation	Climatic warming allows more moisture to be held in the atmosphere.	Increased rainfall and increased intensity of individual rainfall events.
	Hard surfacing (anthropogenic aquitards) and reduced vegetative cover.	Potential reduction and redistribution of effective porosity. Reductions in the potential for evapo-transpiration.
	Funnelling of wind through high storey developments.	Increased evaporation.
Run-off	Hard surfacing (anthropogenic aquitards).	Increased run-off and reduced baseflow to surface water courses; potential to mobilize more sediment; water arrives more quickly increasing the potential for contaminant mobilisation. The reduced run-off times and base flow result in greater flashiness of surface water courses. Layers of hard surfacing, e.g. palimpsests of development may result in multiple levels of perched water.
Recharge	Hard surfacing	Reduction in natural groundwater recharge: exacerbated by silt and sediment clogging; local increases in recharge associated with pipe leakage, and anthropogenic aquifers (e.g. gravel packs to services).
	Made Ground	Increase in near surface storage, particularly in areas underlain by low permeability lithologies.
	Quarrying	Local increases in the extent of bare ground available for recharge.
	Urban development	Leakage from pipes; irrigation water (parks and recreation areas); potential for groundwater level rise beneath urban environments. Granular bedding materials form anthropogenic aquifers.
Freshwater/saline interface	Dewatering	In coastal environments dewatering and lowering of the groundwater table may lead to saline intrusion.
Through-flow and storage		
	Water as a resource.	Lowering of groundwater table and changes to geochemistry, increased depth of unsaturated zone. Increased hydraulic gradients, potential to mobilize contaminants to greater depth. Potable supply can result in cross-catchment transfer of water. The introduction of artificial storage (e.g. reservoir storage to maintain water supply) removes groundwater from aquifers. Overuse may result in derogation of supply.
	Dewatering	In coastal environments dewatering and lowering of the groundwater table may lead to saline intrusion.
	Culverting of watercourses in unconfined aquifers.	Water culverted to allow access across watercourses; may affect recharge processes; potential impact on quality (reduced oxygenation).
	Geothermal energy.	Changes to ground temperature with potential impacts on evapo-transpiration
	Deep construction, e.g. underground tunnels, reservoir construction, landfill.	Compartmentalisation of water; a more irregular water table, and time of vadose zone recharge lengthened by obstacles to flow.
	Discharges, e.g. soakaways.	Ponding of water may alter flow paths.
	Moving water through the unsaturated zone more quickly as a result of underground development and physical disturbance to the ground.	May result in a change to groundwater chemistry, e.g. negative saturation indices move to greater depth in the aquifer, resulting in changes to baseline water chemistry; dry fallout moved deeper into the aquifer.
Discharge		
	Industrial discharge to surface watercourses, e.g. process and mine water, contaminated drainage from industrial units.	Changes to water quality and temperature impacts on ecology.
	Use of abstraction wells.	Alters flow to natural discharge points.

evaluated. However in their review of sustainability in city visions, John et al. (2015) conclude that the visions which are led by city representatives emphasize the functioning of the built environment within the city limits only, and the relationship with the hinterland is weak. Furthermore, they argue that this leads to a reduction in city resilience as experts on the hinterland are not represented and therefore not involved in the design of solutions.

Water supply and disposal form two critical components of the city's metabolism that become more acute as cities grow (Wolman,1965; Jones, 1966), particularly as ecosystem service demand and consumption of resource per capita are outpacing population growth (John et al., 2015). In recent decades the rate of demand for water has been twice the rate of population growth and, under a business-as-usual climate scenario, a 40% global water deficit is predicted by 2030 (UN-WWAP, 2015). As traditional water sources become depleted there is an expectation that cities will need to exploit their hinterlands to broaden their water supply catchment area, utilize marginal water resources and invest in innovation solutions and more advanced technologies to manipulate the natural water systems. The internal city processes that facilitate the supply, consumption and disposal of resources disturb natural systems and alter the urban environment and morphology (Huang and Hsu, 2003). Disturbance of the natural water environment in urban areas and pressure on the ecosystem services it provides is likely to become more pronounced where the physical expansion of cities is occurring at a faster rate than population growth (Sterling et al., 2012; Hunt et al., 2016). As a result inclusion of water within urban metabolism and future cities assessment is common (Rojas-Torres et al., 2014), but explicit consideration of urban groundwater systems is not, which is symptomatic of the fact that ecosystem services provided by urban underground space are not yet appreciated by most city representatives (Hunt et al., 2016).

It is estimated that half of the world's megacities are groundwater-dependent and over 40% of water supply across much of Europe comes from aquifers lying beneath urbanized areas (Wolf et al., 2006). Additionally, groundwater resources in urban areas do not just extend to water for domestic and industrial supply but also to ground source heating. For example, in London it is estimated that 19% of the city's total heat demand (2010) could be derived from ground heat sources (GLA, 2013). The interaction of groundwater with other urban systems, such as infrastructure and surface water networks is well-recognized by expert practitioners and is increasingly on the city agenda, for example in consideration of baseflow provision to urban and peri-urban rivers (blue networks), flood risk, management of blue-green infrastructure (e.g. sustainable drainage systems), adverse effects on underground infrastructure, control of underground construction, and impacts of industrial legacy on water quality. These different examples highlight the range of urban groundwater processes that operate at different temporal and spatial scales and across the rural-urban transition. Here