International Association of Hydrogeologists

Strategic Overview Series

RESILIENT CITIES & GROUNDWATER

KEY MESSAGES

- **groundwater is a major source of urban supply worldwide and aquifer storage represents a key resource for achieving water-supply security under climate change and extended drought**
- **private waterwell construction for urban in-situ self-supply tends to escalate as a 'coping strategy' during periods of inadequate utility water service, but then waterwell use often continues for years as a 'cost-reduction strategy'**
- **urbanisation greatly modifies the 'groundwater cycle' with marked impacts – including periods of declining aquifer pressures (which can cause land subsidence with building and infrastructure damage) and periods of rising water-table (which can lead to groundwater flooding with public health hazards and infrastructure damage)**
- **in the developing world, in-situ sanitation can present a significant groundwater quality hazard which needs more proactive and integrated management**
- **groundwater is often the 'invisible link' between various facets of the urban infrastructure, tending to affect 'everybody' whilst all too often being the responsibility of 'no body'**

Why is groundwater critical for urban water-supply security ?

Urbanisation is the predominant global phenomenon of our time, and groundwater from springs and wells has been a vital source of urban water-supply since the first settlements. In the modern era, groundwater capture using deep waterwells with submersible electric pumps has enabled major growth for urban use worldwide. Factors influencing groundwater use are resource reliability for municipal supply, resource accessibility for private supply, reducing river-intake security with pollution, and relatively low waterwell construction costs. The large natural storage of most aquifer systems has made them a vital resource for assuring water-supply security during past droughts and will be particularly critical in future climate-change adaptation.

Today many countries (from across the EU and USA to Brasil, China, India, Nigeria, Pakistan, Peru and Vietnam) exhibit a high level of dependence on groundwater for urban water-supply, notably for innumerable smaller cities. Urban centres surrounded by high-yielding aquifers, allowing utilities to expand water production incrementally, have often enjoyed lower prices and/or better service levels. It is also important to appreciate the widespread significance of private self-supply from groundwater (not just for industrial purposes but also by residential and commercial users) which in some Brasilian cities reaches 20% of total water use in drought and an even higher proportion in many Indian cities.

RAPID URBAN DEVELOPMENT WITH INCREASING POPULATION DENSITY

This Series is designed both to inform professionals in other sectors of key interactions with groundwater resources and hydrogeological science, and to guide IAH members in their outreach to related sectors.

Why is groundwater a potential threat to the resilience of urban infrastructure ?

Urbanisation greatly modifies the 'groundwater cycle' through causing :

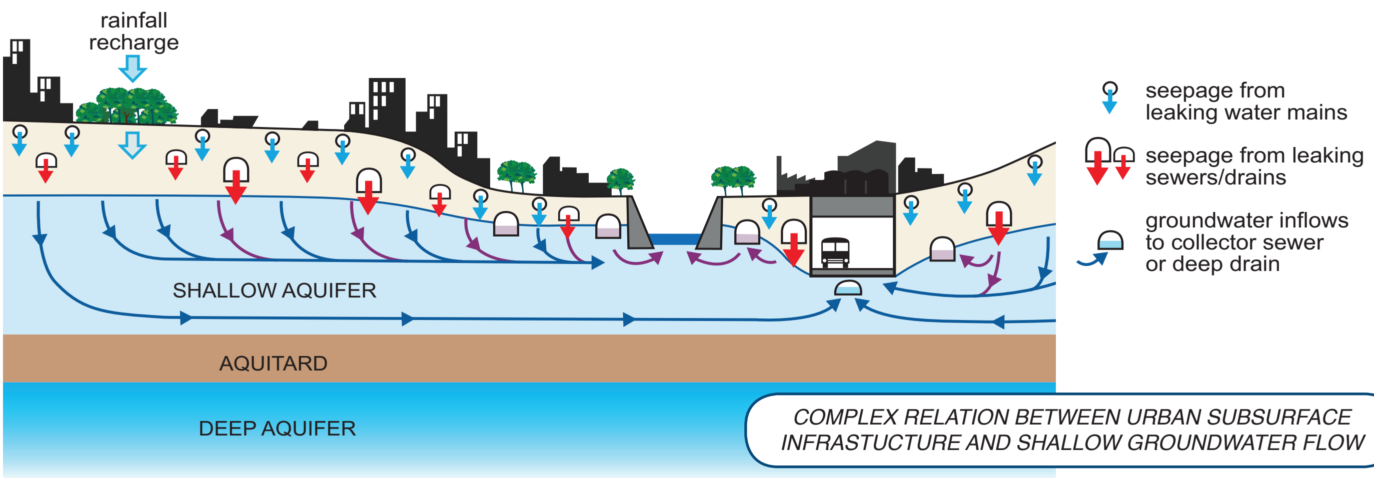
- substantial increases in recharge, because the reduction consequent upon land impermeabilisation is more than compensated by water-mains leakage, wastewater seepage, storm-water soakaways and excess garden irrigation
- large subsurface contaminant load from in-situ sanitation, sewer leakage, inadequate storage and handling of 'community' and industrial chemicals, and disposal of liquid effluents and solid wastes
- major discharge as a result of inflows to deep collector sewers and infrastructure drains.

This modification is in continuous evolution, resulting in changes to the groundwater regime which can seriously reduce the resilience of urban infrastructure.

Despite increased urban recharge rates, there are rarely sufficient groundwater resources within an urban area itself to satisfy the entire water demand of larger cities. If new water-supply sources are not introduced, serious localised aquifer depletion can result with the risk of quasi-irreversible side-effects (such as induced seepage of contaminated water, land subsidence and coastal saline intrusion). Later, in the evolution of major conurbations, when groundwater pumping in central districts often reduces, there can be strong water-table rebound with serious consequences for existing urban infrastructure (eg. Buenos Aires-Argentina & Tokyo-Japan).

In one sense groundwater systems underlying cities represent 'the ultimate sink' for urban pollutants (with nitrates from wastewater and some synthetic hydrocarbons being very persistent), but in practice the extent to which applied subsurface contaminant load impacts groundwater will vary widely with the vulnerability of the aquifer system concerned. It is, however, important that hydrogeological expertise is fully utilised in risk assessment and appropriate clean-up of the legacy of land contamination by industry to minimise groundwater pollution.

Unstable groundwater conditions are always likely to threaten part of the urban infrastructure - but this will vary widely with stage of socio-economic evolution and type of groundwater system involved. In low-to-middle income countries the emphasis tends to be on side effects from intensive groundwater exploitation. But in higher-income countries the third-party impacts of major changes in groundwater regime are usually the concern. In particular, rising water-table and higher peak groundwater levels can cause basement damage and flooding, malfunction of septic tanks and excessive inflows to deep collector sewers. Propensity to 'groundwater flooding' is now a separately recognised risk for insurance companies, which can affect property values.



COMPLEX RELATION BETWEEN URBAN SUBSURFACE INFRASTUCTURE AND SHALLOW GROUNDWATER FLOW

How should groundwater storage be better conserved by urban water-service utilities ?

In future it will be important for the large groundwater storage of most aquifers to be used in a coordinated manner with surface-water sources to improve water-supply security. Most so-called conjunctive use currently practised in developing nations amounts to a 'piecemeal coping strategy'. There are, however, examples of more optimised approaches (e.g. Lima, Peru and Bangkok, Thailand). Effective demand management measures to constrain unnecessary use and reduce 'unaccounted for water', together with managed aquifer recharge (from roof-drainage and permeable pavement soakaways and excess surface water via lagoons or large wells) will be needed widely. All of this will require a 'resource culture' to be cultivated within water utilities.

Additionally establishment of water-utility wellfields outside cities (whose capture areas are declared as drinking-water protection zones) needs to be promoted as 'best engineering practice'. This too often encounters administrative impediments related to fragmented powers between the various municipalities comprising 'metropolitan areas', and improved governance arrangements and economic incentives need to be explored to overcome this problem.

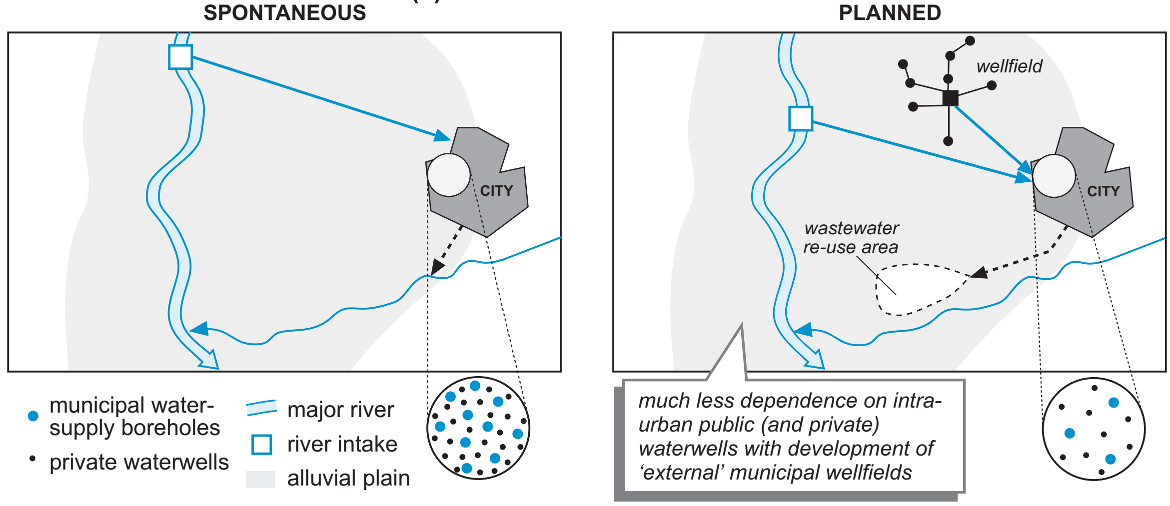
Given the continuous evolution of groundwater use in 'urban aquifers', and some hydrogeologic uncertainty in predicting their precise behaviour, it is desirable to adopt an 'adaptive management approach' to urban groundwater resources. This should be based on continuous monitoring of groundwater levels and quality, and guided by a (periodically updated) numerical aquifer model.

How can groundwater considerations be incorporated in urban sanitation planning ?

The groundwater-sanitation nexus is most relevant in developing nations, where extensive in-situ sanitation presents a significant groundwater quality hazard. In most settings (except for shallow and vulnerable aquifers) there will be sufficient attenuation capacity to eliminate faecal pathogens from percolating wastewater, but the hazard increases markedly with inadequate waterwell construction and/or poor septage management, which are typical of fast-growing anarchical cities. However, troublesome levels of nitrogen compounds and dissolved organic carbon will arise to varying degree, depending on the population density served by in-situ sanitation. For municipal water-supply the problem is often dealt with by dilution through mixing, but this requires a secure source of high-quality water and has absolute limitations because some wastewaters contain a wide array of pharmaceutical and hormonal residues.

URBAN CONJUNCTIVE USE - CONTRASTING SCHEMES OF SPONTANEOUS AND PLANNED DEVELOPMENT

(a) URBAN WATER-SUPPLY



A more integrated approach to urban water-supply, mains sewerage provision and urban land-use is required to reduce the cost and improve the security of the urban water infra-structure. There are numerous practical measures that can be taken to improve the sustainability of groundwater use including :

- prioritisation of recently-urbanised districts for sewerage cover to protect their good-quality groundwater from gradual degradation
- establishment of groundwater protection zones around utility waterwells favourably located to take advantage of parkland
- imposition of better controls for the handling and disposal of industrial effluents and solid wastes to reduce the risk of aquifer pollution.

Groundwater pollution can be reduced by rigorous programmes of septage management and/or deploying dry (eco-sanitation) units in which urine is separated from faeces, with both being recycled. The latter installations are recommended for new urban areas overlying shallow aquifers, but they are not the universal solution to ground-water contamination because large-scale retro-installation in existing dwellings is very costly.

An important corollary is making better use of increasing wastewater resources generated by wider sewer coverage – this could be through re-use for amenity and agricultural irrigation which is spatially planned and appropriately controlled so as to minimise public health hazards,including incidental pollution of groundwater in potable use.

How can private in-situ use of urban groundwater be rendered more secure ?

Private capital investment to access groundwater in-situ for urban self-supply often mushrooms during phases of rapid urbanisation and/or periods of inadequate utility water-supply. This is essentially a 'coping strategy' by multi-residential properties, commercial and industrial enterprises. Water users tend to take their supply from multiple sources according to their availability and relative cost with much more expensive tankered water as the last resort. Private self-supply from groundwater is then likely to continue by many users as a 'cost-reduction strategy', when availability of utility supplies improves.

Private groundwater use widely represents a significant proportion of the total urban water-supply 'actually received by users', and has major implications for planning investment in municipal water infrastructure (eg. Sao Paulo,& Fortaleza-Brazil, Kathmandu-Nepal, Bangalore & Auranabad-India). Although the 'economy of scale' can be poor, the cost of water-supply from this type of source often compares favour-ably with the tariffs implied by full cost-recovery for new utility surface water-supply schemes. Whether private residential groundwater use presents a serious threat to the user will depend on the type of anthropogenic pollution (or natural contamination) present, and the type of water-use concerned. A critical assessment of

PRIVATE URBAN IN-SITU GROUNDWATER USE - OVERVIEW OF BENEFITS AND RISKS

BENEFITS

- much improves access and reduces cost for some groups of water-user (but not poorest unless waterwell construction/ operation costs are underwritten)
- highly appropriate for 'non-quality sensitive uses' (garden irrigation, laundry, cleaning, cooling systems, etc)
- does not cause serious resource depletion (except in confined aquifers) and recovers major water-mains leakage
- reduces pressure on municipal utility supplies, especially for demands of difficult location or with temporal peaks

RISKS

- interaction with in-situ sanitation can cause health hazards and make control of waterborne disease more difficult
- requires special caution if industrial pollution or serious natural contamination of groundwater present
- inadequate waterwell completion can lead to transfer of contaminants from shallow to deeper aquifers
- intensive self-supply by more affluent urban dwellers can produce complex knock-on effects and seriously reduce utility revenue collection

urban waterwell use practices and impacts is required by public administrations to formulate balanced policy.

An emerging policy question is under what circumstances the risks or inconveniences of private residential self-supply from urban groundwater justify attempts to ban the practice. Many private waterwells are, at best, unregulated and at worst illegal. In the longer run this is counterproductive for the private user and the public administration, but can be regularised by management interventions such as :

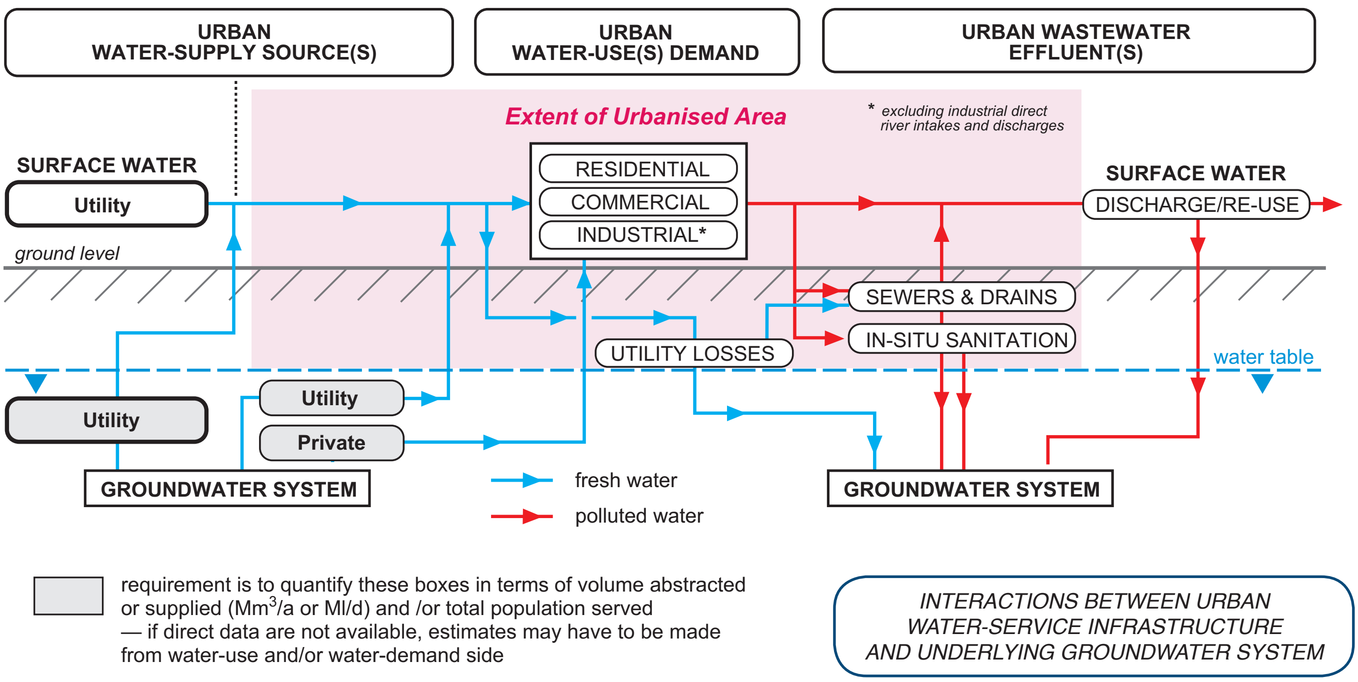
- using advances in geographical positioning and data capture to locate waterwells
- registering commercial and industrial users, together with residential use for apartment blocks and housing estates, and charging for groundwater abstraction by waterwell pump capacity or metering sewer discharge
- issuing water-quality use advice and health warnings to private waterwell operators, and if pollution is severe declaring sources unsuitable for potable use
- gaining civil-society commitment through effective participatory mechanisms and incentives for 'self-monitoring'.

How can the 'vacuum of responsibility' for urban groundwater be filled as a basis for integrated management ?

Groundwater resources around urban centres are influenced by a complex array of local development decisions, which are rarely viewed in an integrated fashion, including :

- authorisation of waterwell drilling/use (if at all by water resource agencies)
- production and distribution of water-supply (mainly by water-service utilities)
- urban infrastructure and land-use planning (by municipal government offices)
- installation of sewered sanitation, disposition of liquid effluents and solid wastes (by environmental authorities, public-health departments, water-service utilities).

While many problems are predictable, few are actually predicted, because of a vacuum of overall responsibility and accountability. Frequently 'one group's solution tends to become another group's problem'! There is a clear need for groundwater considerations to be integrated when making decisions on infrastructure planning and investment, but institutional responsibility is often split between various organisations, none of which is



RESILIENT CITIES & GROUNDWATER

equipped to take the lead because :

- water-resource agencies/committees rarely have the capacity to cope with urban development dynamics
- urban water utilities are often 'resource illiterate' despite increasing groundwater dependence
- urban land and environment departments have a poor understanding of groundwater.

The strategic importance of urban groundwater is not yet reflected by sufficient investment in management and protection of the resource base. In this context groundwater professionals need to raise awareness of the economic value of groundwater and reveal key issues in the political economy of resource governance. Governments, from national to local level, need to seek realistic policies and effective institutions to address this issue. They will require political leadership, improved stakeholder participation and be informed by sound hydrogeological science. Moreover, the dynamics of urban development and its relationship with groundwater are such as to merit the formation of a 'cross-sector urban groundwater consortia' (or standing committees) of all major stakeholders and regulatory departments/agencies. Such consortia should be tasked with communicating groundwater issues at the political and executive level, and must be empowered and financed to define and implement a 'priority action plan', and should be provided with a sound technical diagnostic (from an appropriate group of institute and university specialists).

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PRIORITY ACTIONS

- **use groundwater more efficiently and sustainably for urban water-supply, such that aquifer storage can continue to play its full role in water-utility strategies for climate-change adaptation**
- **promote as 'best engineering practice' the establishment of water utility wellfields outside cities (declaring their 'capture areas' as drinking-water protection zones)**
- **adopt an 'adaptive management strategy' for urban groundwater resources, recognising that aquifers are in continuous evolution with some hydrogeologic uncertainty over prediction of their precise behaviour**
- **take a more integrated approach to urban water-supply, mains sewerage and sanitation, stormwater drainage, and urban land-use to reduce the cost and improve the resilience of the urban water infrastructure**
- **promote broad assessments of urban in-situ waterwell use by the public administration to allow the formulation of a balanced policy for private self-supply from groundwater**
- **establish 'cross-sector urban ground water consortia' (of all major stake holders and regulatory agencies) informed by adequate groundwater system monitoring, and empowered to define and implement a priority management action plan**

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