

Sustainable Groundwater Management Contributions to Policy Promotion

Strategic Overview Series Number 3

Urban Groundwater Use Policy balancing the benefits and risks in developing nations

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This overview provides a strategic assessment of trends in the public and private use of groundwater for urban water-supply in developing cities – and an analysis of its benefits to users and the broader community, its risks in terms of compromising resource sustainability and of public-health hazard arising from urban pollution, and its implications as regards water utility investments. It is based primarily upon GW•MATE field experience from World Bank-supported projects, especially in Brasil and India, and more widely in Latin America and Asia, together with preliminary information from a number of African cities. This experience is synthesized to identify key policy issues, and to define appropriate policy responses and institutional approaches for more rational and secure resource use.



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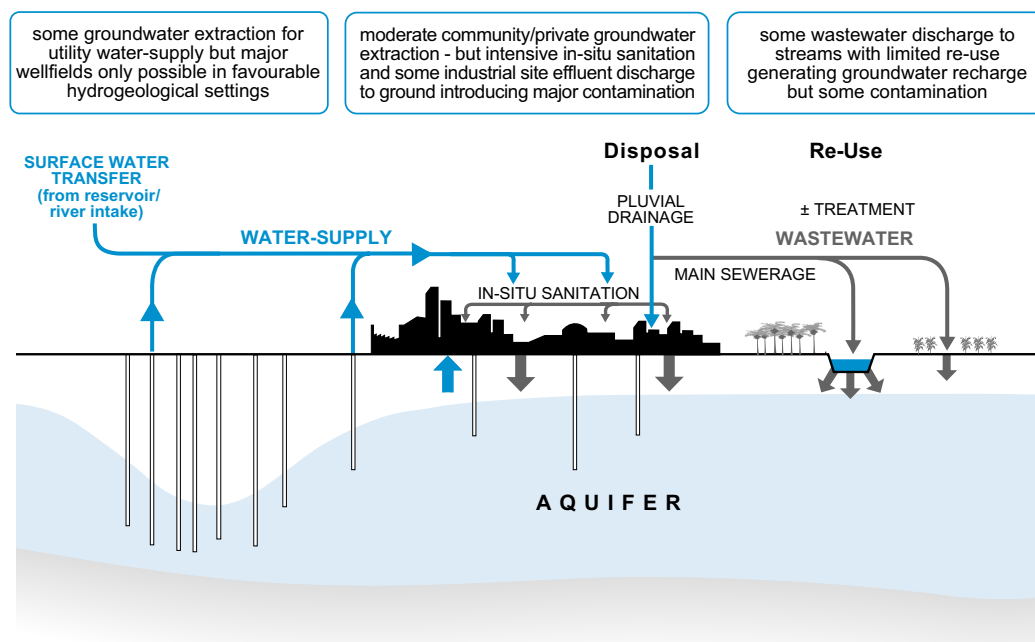
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CONTEXT FOR POLICY DEVELOPMENT

Drivers of Urban Groundwater Use

- There is considerable evidence to suggest increasing dependence on groundwater for water-supply in developing cities. This is occurring in response to population growth, accelerated urbanization trends, increasing per capita use, higher ambient temperatures and reduced security of river-intakes with climate change – and is facilitated by the generally modest cost of waterwells. Unfortunately there are no systematic and comprehensive data to quantify this trend, but it has been approximately estimated that more than 1.5 billion urban dwellers worldwide currently rely on groundwater.
- Those urban centres underlain and/or surrounded by high-yielding aquifers, of sufficient potential to provide a major component of utility water-supply, usually have better mains water-service levels and lower water-prices – because ready access to groundwater has allowed utilities to expand their water-supply production incrementally at relatively low cost in response to rising demand. This (and the fact that major aquifers often have deeper water-tables implying higher waterwell construction cost) generally tends to result in less private residential in-situ use of groundwater. But industrial and commercial use is often present and, in situations where municipal water-supply service remains inadequate, private operators sometimes develop local domestic water distribution systems (reticulated or tankered) based on urban waterwells (eg : Asuncion-Paraguay – **GW•MATE Case Profile 3**).
- However, there are rarely sufficient groundwater resources within the urban area itself to satisfy the water-supply demands of larger cities, and resource sustainability thus often becomes an issue. This natural scarcity is sometimes aggravated by competition with use for irrigated agriculture. Moreover, groundwater quality may also be threatened by inadequately-controlled urban pollution pressures, especially given the close connection between wastewater handling, disposal or reuse and underlying phreatic groundwater (Figure 1).
- The growth in urban groundwater use is not restricted to cities with ready access to high-yielding aquifers but also widely occurs in situations where the utility water-supply is imported from a distant surface-water source of poor reliability or at high cost. This may result in the mushrooming of private in-situ waterwell construction as a result of poor (present or historic) municipal water-service levels and/or high water prices.
- In these cases in-situ private self-supply from groundwater widely represents a significant proportion of water ‘actually received by users’, and its presence thus has major implications for municipal water utilities. The construction and operation of private waterwells by some groups of residential consumer also signifies a ‘willingness to pay’ for more reliable water-supply – and raises the question as to whether municipal water-service utilities should make more effort to ‘capture this potential income’ through improving their service-levels directly by reduction of distribution leakage losses (and other forms of ‘non-revenue’ mains water).

Figure 1 : Unconfined groundwater and its interaction with urban infrastructure



- Thus, in order to pursue policy development rationally it is necessary to distinguish between the following general cases :
 - cities where an important part of the municipal water-supply is derived from groundwater
 - cities where most municipal water-supply is drawn from external surface water sources but groundwater is intensively used for in-situ private self-supply
 albeit that a in the former case some private in-situ supply may also exist – depending on hydro-geological conditions, waterwell costs, municipal water-supply reliability and cost, etc.

Regional Variations in Urban Groundwater Dependency

- The experience on which this paper is based includes conducting surveys and/or considering data from a substantial range of developing cities globally (Table 1), with special emphasis on Brasil and India. Whilst there are significant regional (and indeed local) variations in the evolution of urban water-supply provision and dependence upon groundwater, there is also a ‘common thread’ related to resource availability for municipal use and supply accessibility for private use.
- In Brasil, and other Latin American countries, some urban water-service utilities are heavily dependent upon groundwater. However in cities where utilities primarily depend on imported surface water-supplies, large numbers of private waterwells have also been developed (mainly in the 1990s) in response to urban water-supply crises during extended drought. Such waterwells continue to be used today (and many new ones constructed) as a ‘cost-reduction strategy’, because the groundwater they provide is considerably cheaper than the corresponding domestic water-supply tariff of the municipal water-utility.

Table 1: Characteristics of cities whose groundwater use issues considered in formulation of policy diagnostic**

CITY	AQUIFER TYPE	GROUNDWATER USE POLICY & MANAGEMENT ISSUES	INSTITUTIONAL PROVISIONS FOR MANAGEMENT
SOUTH AMERICA	Fortaleza * +	rationalise private residential/commercial self-supply given improved municipal water-service provision	state water resources planning secretariat engaging water-service utility on policy definition
	Recife (Norte)	move to planned conjunctive use for municipal sources to reduce risk of coastal saline intrusion	state water resources planning secretariat trying to promote action with water-service utility
	Natal *	municipal utility highly groundwater-dependent but serious pollution from uncontrolled urbanization	state water resources planning secretariat trying to coordinate action with various stakeholders
	Ribeirao Preto * +	municipal utility and industry totally groundwater-dependent but serious local depletion/pollution risks	state water resources agency leading on policy formulation via basin stakeholder committee
	Rivera-Santana do Livramento +	municipal utilities highly groundwater-dependent but significant pollution risk from uncontrolled urbanization	transboundary aquifer management committee formed but continuity/authority questionable
	Lima *	major investment in successful transformation to planned conjunctive use with local aquifer stabilization	municipal water utility delegated to implement resource management plan by national ministry
	Asuncion +	control of many small private water-supply enterprises using shallow and potentially-polluted groundwater	national water resources agency + water service regulator aware but lack operational capacity
ASIA	Buenos Aires +	major reduction in municipal/industrial groundwater use resulted in serious drainage/sanitation problems	no clear responsibility but state water infrastructure ministry considering how to address
	Delhi	rationalize private residential/commercial self-supply with investment to improve municipal water-service	no clear responsibility but state + municipal government have formed working group
	Lucknow * +	move to planned conjunctive use for municipal sources to reduce local aquifer depletion	state water resources agency starting to engage with municipal utility on policy formulation
	Aurangabad * +	rationalise private residential/commercial self-supply with investment to improve municipal water-service	no clear responsibility but state water infrastructure ministry considering how to address
	Bangkok * +	major successful effort to reduce groundwater use, stabilise aquifer and mitigate land subsidence	national groundwater agency led on policy formulation/practical management measures
AFRICA	Nairobi +	rationalise private industrial/commercial/residential use to stabilize aquifer and treat more as strategic reserve	no clear responsibility but national water resources ministry considering how to address
	Dar-es-Salaam	develop major external wellfields to permit planned conjunctive use for municipal utility sources	water basin agency working with municipal utility to elaborate development/management plan

** GW•MATE involved directly in these cities sometime during period 2001-10

* those cities subjected to detailed investigation and assessment and/or + with GW•MATE Case Profile on website

- In many cities of Peninsular India individual private waterwells for direct residential self-supply are ubiquitous as a ‘coping strategy’ in the face of very poor utility water-service levels (often struggling to reach the 4-in-24 hour supply level), and cumulatively provide a large proportion of the water actually received by urban users. While the ‘economy of scale’ is poor, the low-cost of shallow waterwell construction into weathered hard-rock aquifers is attractive and the cost of water-supply from this type of source compares very favourably with the tariffs implied for cost-recovery in new surface water-supply schemes. Although aquifers are invariably ‘over-exploited’ and waterwells often fail in drought, their existence greatly reduces dependence on expensive water-tanker supplies. In contrast on the Indo-Gangetic Plain most municipal water utilities use groundwater sources, at least in part conjunctively with surface water sources, and in general their water-service levels are superior to those in Peninsular India.
- In Sub-Saharan Africa only a few large urban water-service utilities make major use of groundwater (eg. Abidjan, Bamako, Dodoma & Lusaka) – but waterwells for direct water collection (or sometimes reticulation to stand-posts) have widely become the fastest-growing source of urban water-supply in the struggle to meet burgeoning demand from very rapid population growth. The general situation and associated issues are described in more detail in **Box A**.

GROUNDWATER AND THE CITY – AN INTIMATE BUT UNSPOKEN RELATION

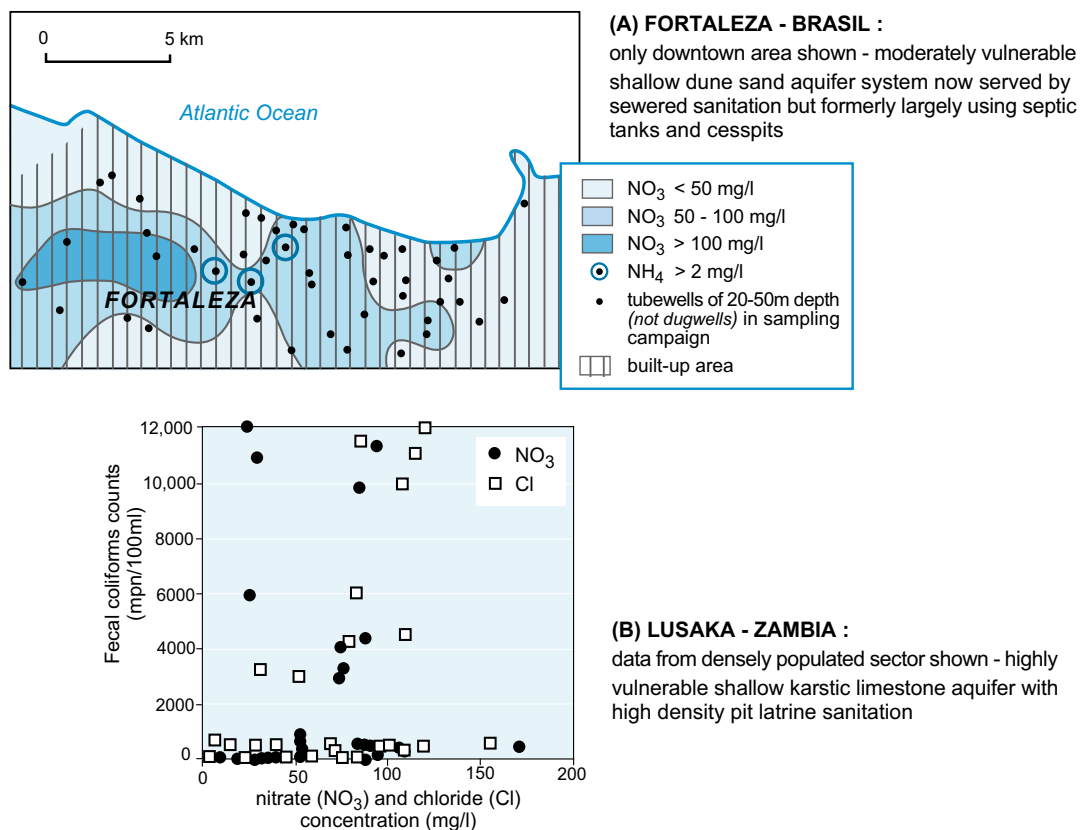
- Urbanisation greatly modifies the ‘groundwater cycle’ – with some benefits and numerous threats. The processes characteristic of urbanisation and industrialisation usually have a marked impact on groundwater in aquifers underlying cities, and in turn man-made modifications in the groundwater regime can have serious impacts on the urban infrastructure.
- The associated problems can be very costly and surprisingly persistent – and while many of these problems are ‘predictable’ few are actually ‘predicted’. All too often, where groundwater is concerned, without integrated vision and planning in the urban environment ‘one person’s solution tends to become another person’s problem’! It is thus important to establish, and periodically refine, the conceptual hydrogeological model of major conurbations and important cities as a platform for groundwater use policy formulation.

Impact of Urbanisation on Groundwater – the Sanitation Nexus

- In general terms it can be said that urbanisation has a direct interaction with groundwater underlying cities (Figure 1) through :
 - substantially modifying, and generally increasing, groundwater recharge rates – the reduction in natural rainfall recharge through land-surface impermeabilisation usually being more than compensated by physical water-mains leakage, by infiltrating pluvial drainage and by the ‘return’ of wastewater via in-situ sanitation and main-sewer leakages, especially in cases where part of the water-service infrastructure is relatively old and/or poorly constructed and the municipal water-supply is

- largely ‘imported from external sources’, although not in cases where the mains water-supply service levels are very deficient
- greatly increasing contaminant loading, as a result of in-situ sanitation (especially relevant in the developing-nation context) and to lesser degree sewer leakage, and also inadequate storage and handling of ‘community’ and industrial chemicals, and disposal of liquid effluents and solid wastes.
 - In-situ sanitation of major urban areas presents a significant groundwater quality hazard, which needs to be recognised and managed. This problem is further accentuated by the fact that self-supply from groundwater is generally more intensive where access is easiest – namely in the presence of shallow unconfined aquifers which are the more vulnerable to pollution.
 - In most aquifer types, except the extremely vulnerable, there will be sufficient natural groundwater protection to eliminate faecal pathogens in percolating wastewater from in-situ sanitation – although the hazard can increase markedly with sub-standard waterwell construction and/or certain types of informal or illegal sanitation and waste disposal practices. However, elevated (and often troublesome) concentrations of N compounds (usually nitrate) and DOC in groundwater will also be present to varying degree according to the population density served by in-situ sanitation and can penetrate to considerable depths in the aquifer (Figure 2). Such groundwater pollution can persist for years after the source of contamination is removed, by installation of main sewerage or other alternative sanitation.

Figure 2 : Groundwater quality and urban in-situ sanitation –examples of impacts



Box A

SUB-SAHARAN AFRICA

MAKING BEST USE OF GROUNDWATER TO MEET THE PRESSING DEMANDS OF EXPANDING URBAN POPULATIONS

Rapid growth of urban population (widely at 2–7%/a) and water demand (up to 10%/a) is a reality in Sub-Saharan Africa, and is likely to be further accentuated in some climate-change scenarios. These trends do not just affect megacities but are also pronounced in hundreds of medium-sized towns. Where suitable aquifers are present, expansion of groundwater use is usually the preferred response – in terms of time taken, capital outlay and drought reliability. However, given the paucity of reliable data, it is far from a trivial task to establish the present level and current trends in groundwater use. The World Bank – Africa Infrastructure Diagnostic (which used a 2007 database incorporating 63 large-scale surveys in 30 countries) reveals substantial variation between more and less urbanized countries (Table A1) but the following general conclusions can be reached :

- on average only 38% of urban dwellers are served by mains water-supply piped to their dwelling, but a further 29% have access to municipal stand-posts within 500 m (some supplied from groundwater)
- 24% of urban water-supply (by user numbers not volume of abstraction) is groundwater directly collected from waterwells constructed by municipal, community or private initiative – and this is the most rapidly-growing category at 1.5 %/a on average and over 5%/a in some countries
- on average 33% of urban populations are served by waterborne sewerage (although the nominal proportion of urban area with coverage is over 50%), but 59% are dependent upon in-situ sanitation (mainly the basic pit latrine with some septic tanks) and about 8% have no sanitation system whatsoever.

Table A1: Survey of sources of urban household water-supply in selected Sub-Saharan African countries

COUNTRY	pipelined water-supply	standpoint access	collection waterwell	water vendors
Burkina Faso*	32%	52%	13%	1%
Ethiopia	52%	37%	6%	1%
Ghana	34%	38%	21%	3%
Malawi	31%	42%	24%	1%
Nigeria*	15%	17%	48%	11%
South Africa	88%	10%	2%	0%
Tanzania	22%	45%	19%	8%
Uganda	14%	47%	35%	2%

* countries with long-term tradition of groundwater use and dependency

Contrary to operational recommendations only a minor proportion of pit latrines are emptied, with most being connected eventually to supplementary pits – implying a large contaminant load to groundwater in shallow aquifers (especially in highly-populated areas). The significance of pit-latrine sanitation for groundwater quality is well established – with the problem of high nitrate concentrations coupled with other chemical and fecal contamination having been identified in small towns of eastern Botswana over 25 years ago. The risk of fecal pollution, however, could and should be limited to the most vulnerable hydrogeological conditions – but it currently remains a much more widespread problem because of inappropriate sanitation unit design/operation and inadequate waterwell sanitary completion.

The most-probable future trend will be expansion of low-cost facilities, such as boreholes/dugwells (with limited reticulation to standposts where feasible), coupled with improved pit latrines for sanitation. However, in Sub-Saharan Africa waterwell construction costs still remain high – for example small-diameter shallow tubewells with simple plastic casing equipped with handpumps are costing US\$ 3,000-5,000. It is likely that these costs would usually have to be shared across a substantial number of urban dwellings (hopefully to supply 100-250 people), and thus most urban waterwell construction will be using national, state or municipal funding, together with that of international donors and charities.

Expansion of Small Town Supplies : Urban population growth and shallow aquifer pollution is widely leading to a need to locate/develop waterwells with sufficiently large yields and assured quality to support continuous pumping and reticulation to urban standposts. Concomitantly a high priority needs to be put on improved groundwater resource and vulnerability appraisal, efficient waterwell design, aquifer recharge and waterwell source protection areas – together with much improved monitoring to provide a sound basis for future expansion of municipal water-supply services.

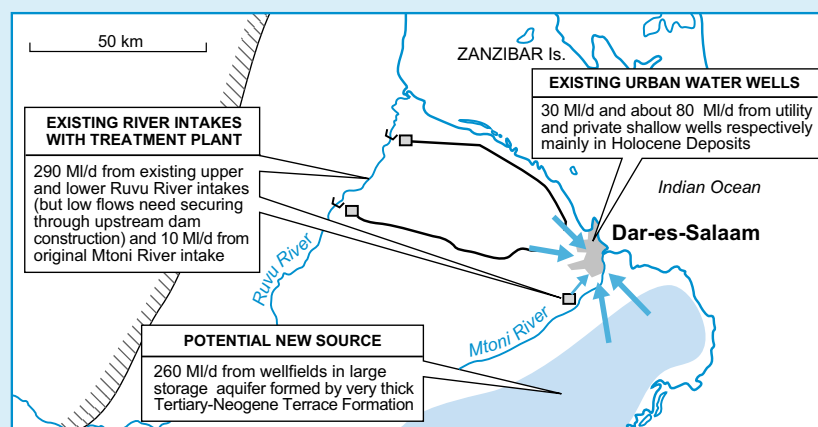
Growth of In-Situ Self-Supply : The demand for self-supply from groundwater by residential, commercial and industrial users is likely to grow substantially – even in hydrogeological settings offering only small well yields and regardless of quality. Thus pragmatic ways need to be found of ‘living with’ urban quality deterioration problems through :

- providing incentives for logical types of private urban groundwater use (such as domestic toilet flushing, laundry, amenity irrigation, non-sensitive industries, cooling water, etc)
- being aware of potential long-term operational and financial problems created by large-scale residential in-situ self-supply, and the potential public health hazard in highly vulnerable aquifers
- considering measures to reduce subsurface contaminant load (especially regular emptying of existing in-situ sanitation facilities, introducing dry or eco-sanitation units, prioritizing mains sewerage in areas of high aquifer pollution vulnerability and/or industrial effluent generation)
- enhancing aquifer recharge by rain-water harvesting from roof-top and paved areas.

Development of New Municipal Sources : Where hydrogeological settings are favorable (albeit a minority of cases such as Addis Ababa and Dar-es-Salaam) there may be potential for significant new groundwater resources to be developed by wellfields in the hinterland of important cities/towns (Figure A1). This has the major attraction of providing access to large natural storage reserves that can be used conjunctively with existing surface water sources, to act as a ‘buffer’ in adaptation to climate change, but will require substantial investment, a systematic approach (including stepwise investigation and phased monitored development) and concomitant action to preserve recharge areas.

In all cases more effort needs to go into defining appropriate policies for urban groundwater use and on evaluating, managing, conserving and protecting resources. In fast-growing urban centres this will normally require an integrated effort, involving a standing committee of empowered representatives from the water resource regulator (where such exists), the water utility, the public-health authority and the municipal land-use planning agency, a mechanism for community consultation and a technical support group to evaluate specific issues and potential conflicts. Professional expertise on how to evaluate, develop, manage and protect groundwater resources has declined in some parts of Sub-Saharan Africa since the 1980s (especially in government offices) and the human resource dimensions of addressing the issue of ‘making better use of urban groundwater resources’ cannot be overlooked.

Figure A1: Existing Water-Supply and Prospective New Groundwater Source for Dar-es-Salaam - Tanzania



- Groundwater pollution can be reduced substantially by deploying so-called dry or eco-sanitation units, in which urine is separated from faeces and not discharged to the ground. And while such installations are highly recommended for new urban areas overlying significant shallow groundwater resources, their deployment as a universal solution to the groundwater contamination problem has some specific limitations since :
 - retro-installation in large numbers of existing properties is not straightforward
 - it is unsuitable for certain cultural groups who use water for anal cleansing.
- A separate question is leakage from mains sewerage systems, which is always negative from the point-of-view of groundwater resource quality but rarely receives attention from water-service utilities, since they do not see investments here as having any direct return to them by increasing water available for sale to consumers. Moreover, without adequate maintenance to reduce leakage losses, sewerage systems may not afford the protection to groundwater which is often assumed.

Effect of Groundwater on Urbanisation

- Beneath major urban areas the groundwater flow system itself can be substantially modified, and such modifications evolve considerably with time :
 - in the earlier phases of rapid urban growth excessive abstraction of groundwater resources widely results in falling water-tables, which in some hydrogeological settings can also cause intrusion of saline groundwater into freshwater aquifers or land subsidence due to the compaction of interbedded unconsolidated aquitards
 - in later stages of evolution of major urban areas abandonment of waterwell pumping in central districts can result in strong water-table rebound with serious impact on the established urban infrastructure, as a result of such factors as the decline or migration of 'heavy industry', transformation from high-density residential to commercial use, groundwater pollution fears and the 'import' of major new water-supplies – this phenomena is well illustrated by the experience of the past 15 years in Greater Buenos Aires (**Box B**).

Vacuum of Institutional Responsibility for Groundwater

- All too often there is a vacuum of responsibility, and therefore of accountability, for urban groundwater – with at best responsibility being split between a number of organisations none of which take a lead in coordinating necessary management actions. These organisations can include : municipal water-service utilities, provincial/state government water-supply and public-health engineering departments, central and/or provincial/state/basin groundwater resource agencies and environment protection/pollution control agencies.
- The reality is that the large majority of private urban waterwells are unregulated or illegal. This situation has developed as a result of the inadequate capacity of groundwater resource regulatory agencies and/or deliberate 'non-regulation' of individually small activities – bit it is counterproductive both from the point-of-view of the private user and the public administration and adds to the problem of stimulating a rational policy dialogue and action plan on urban groundwater. The same can be said of much wastewater and effluent disposal to the ground.

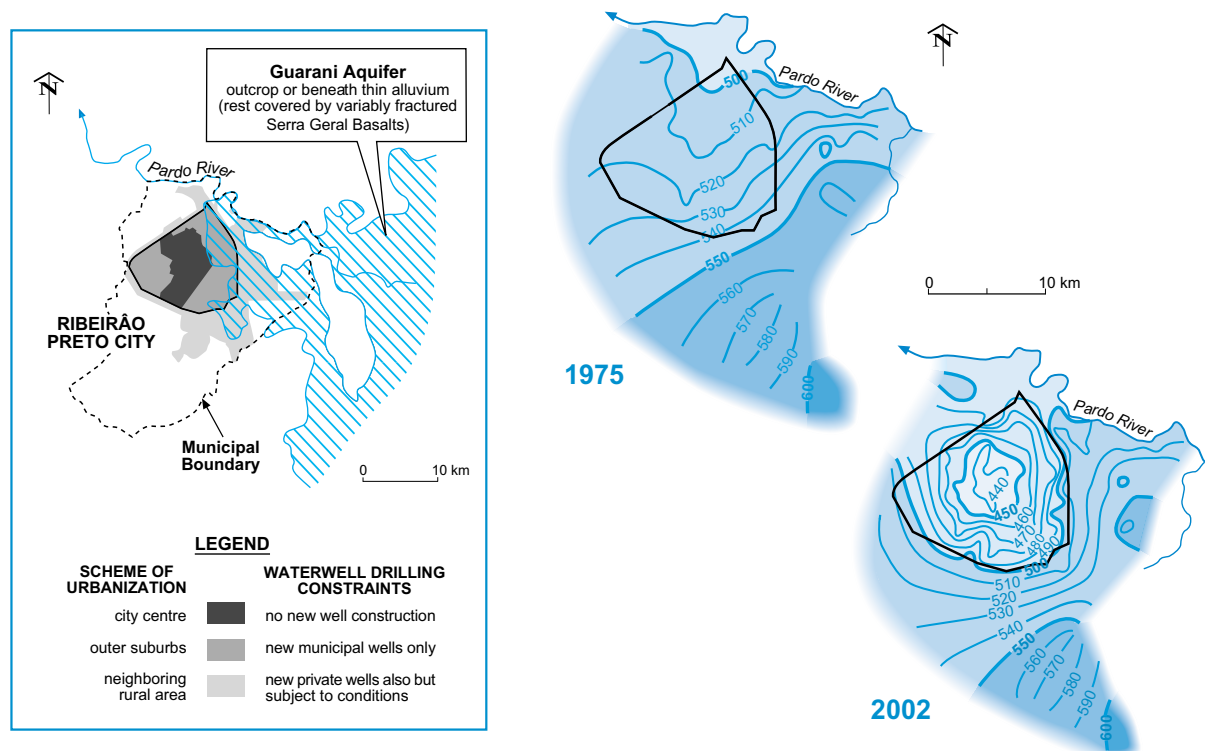
- Given the very meagre institutional capacity in most developing countries and difficulty in dealing with vested interest, the prospect of establishing a comprehensive groundwater rights system is generally low. Thus any level of regulatory measure must be complemented with stakeholder participation – and to promote this it is essential to have up-to-date waterwell user and ‘potential polluter’ inventories, which include not only technical, but also economic and social, information.

GROUNDWATER USE FOR MUNICIPAL WATER-SUPPLY

Identification of Main Issues

- For those cities and large towns underlain and/or surrounded by a high-yielding aquifer, which provides a major component of utility water-supply, there are rarely sufficient resources within the political boundary of the urban municipality to satisfy in full their water-supply demand. In consequence the preferred policy should be to spread out their groundwater abstraction over larger areas. Additionally urban groundwater quality may be under threat from potentially-polluting activities, and thus the key issues which require consideration are :
 - Sustainability** – intensive groundwater abstraction leading to serious localised aquifer depletion especially (but not only) in semi-confined systems (eg: Figure 3), with risk of induced seepage of contaminated water and saline intrusion or land subsidence in coastal settings – **Box C & D** illustrate this type of condition from the northern part of the Recife conurbation in Brasil and for Lucknow City in India.

Figure 3 : Evolution of groundwater table deline in Ribeirao Preto (SP) - Brazil with current waterwell restriction zones as the regulatory response



Box B

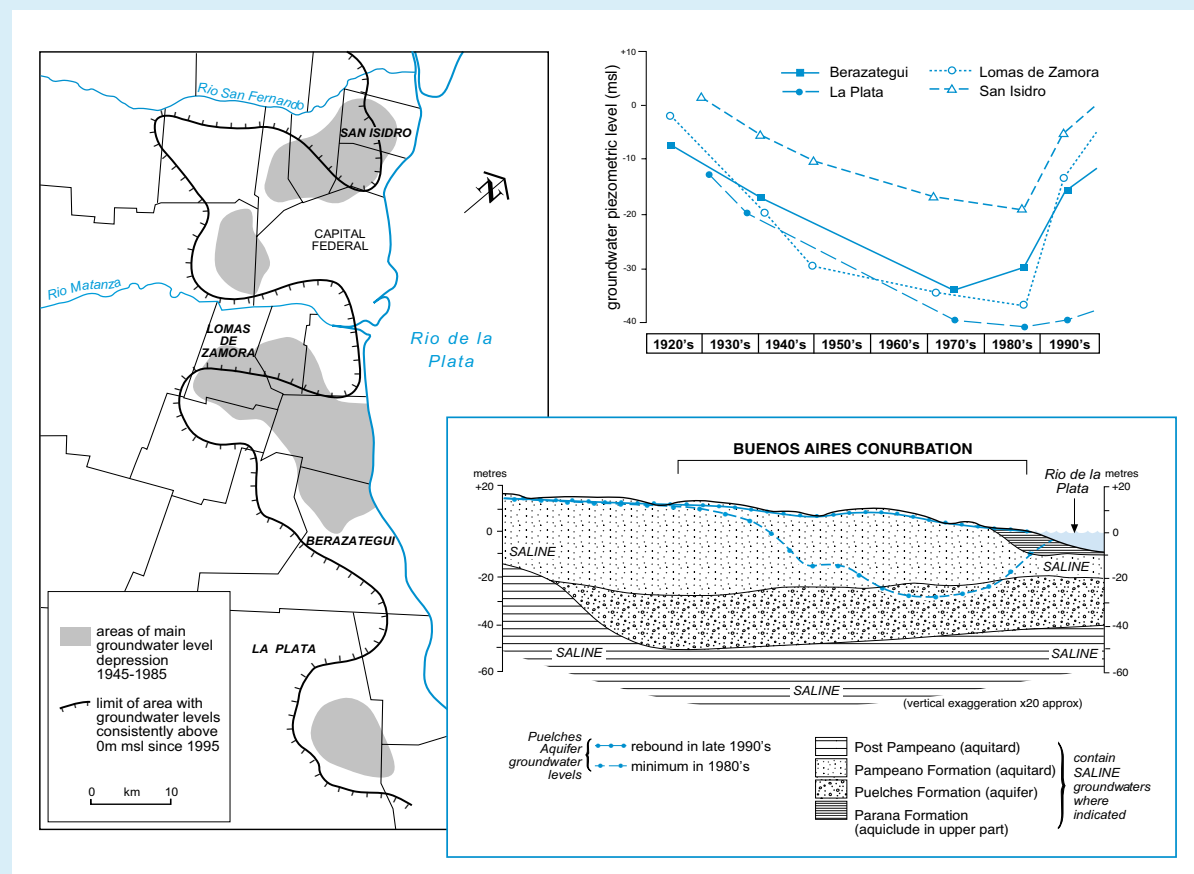
BUENOS AIRES - ARGENTINA

A SALUTORY LESSON ON THE RISKS OF URBAN WATER-TABLE REBOUND AND APPROACHES TO MITIGATION

Buenos Aires, and neighboring areas of the Pampa Humeda, have long experienced surface water drainage problems following periods of exceptionally intense rainfall, but since the early 1990s the drainage problems have been associated with water-table rebound – a relatively new, insidious, and costly phenomenon. A broad belt along the southern side of the Río de la Plata estuary (including the Buenos Aires Conurbation) is underlain by a blanket of Pampeano loess with a ‘relic dune structure’, acting as a ‘leaky surface aquitard’ above the much more permeable Puelches Aquifer (Figure B1). This Aquifer is of low-to-moderate pollution vulnerability but would expect to experience groundwater contamination by persistent pollutants discharged continuously. It is, therefore, not surprising that extensive contamination by nitrate was observed in those districts largely dependent on in-situ sanitation – with levels widely exceeding 50 mgNO₃/l and more locally 100 mgNO₃/l, and that localized pollution by persistent synthetic industrial organic compounds (DNAPLs such as TCE) has also been locally recorded.

Over many decades a significant proportion of Buenos Aires water-supply was obtained from groundwater, and this depressed the aquifer piezometric surface over a wide area to -20 m MSL (or more) (Figure B1). Until the late 1980s the main water-service utility operated some 250 wells with an overall production capacity in excess of 500 Ml/d – and to this must be added direct groundwater abstraction from a large number of industries and larger numbers of (individually small) private domestic wells, together with significant use for amenity irrigation. As a result of growing

Figure B1 : Hydrogeological conditions and groundwater level evolution in Greater Buenos Aires



concern about diffuse groundwater pollution (mainly nitrate) and to lesser degree saline intrusion, the water-service concessionaire (AASA) was required to improve water-supply quality to WHO potable standards by importing large volumes of treated surface water and progressive closure of most waterwells within the main urban area. Thus by 2003 AASA only had 30 waterwells operationally-equipped, which were used only to maintain water-supply pressure at the limits of their network. Since the early 1990s this reduction in abstraction has led to the ‘rebound’ of the water-table (Figure B1). There is little information on abstraction by other groundwater users, but this is also believed to have reduced substantially due industrial decline and pollution fears – the exception being other water-service concessionaires, who continue to depend on groundwater and thus water-levels remain depressed in the areas where these companies operate (eg. La Plata).

The serious groundwater drainage problem which occurred from the late 1990s, over extensive areas of the Buenos Aires conurbation (primarily the western and southern suburbs with a total population of over 3.5 million), with malfunction of in-situ sanitation systems, overloading and overflowing of sewers, flooding of basements, rising damp in domestic dwellings and disruption to parts of the urban infrastructure, is the result of the combination of the following factors:

- import of very much larger volumes of mains water-supply, a substantial proportion of which is lost or discharged to the ground by mains leakage and via extensive in-situ sanitation
- corresponding reduction of groundwater pumping, which incidentally provided good urban ‘under-drainage’
- increased annual rainfall (perhaps as much as 20% in the 1990s).

This has given rise to a significant health risk, much social distress and major economic cost in the districts concerned. The importance of the change of water-supply in the urban groundwater balance cannot be over-emphasised – a gross water-supply rate of 1 m³/d per 500 m² (not excessive by Buenos Aires standards) represents 730 mm/a (all of which will be discharged to the ground in areas without mains sewerage), compared to a natural excess rainfall of 240 mm/a (some of which runs-off from paved surfaces).

The effectiveness of mitigation measures to address drainage problems is strongly correlated with the hydrogeological conditions and in particular the presence of the generally low-permeability surface Pampeano Formation. A detailed technical and economic study of the feasibility of renewing production well operation to effect the required groundwater drainage (and reduce surface water import to the urban area) was appropriate and would include the following :

- aquifer numerical modelling to simulate the original decline of groundwater levels and the rebound following the major reduction in groundwater pumping, (including variations in recharge from the water infrastructure)
- definition of the configuration of pumping wells for the required lowering of groundwater levels, reconciling this with availability of AASA and industrial wells to minimise the need for new waterwell drilling
- groundwater sampling and analysis for the waterwells concerned (as regards salinity, F, As, NO₃, NH₄ and NAPLs) to assess potential uses and blending/treatment requirements.

To promote the systematic evaluation and integrated solution of the groundwater drainage problem it is essential to establish institutional and financial arrangements which will enable the ‘key actors’ to participate in a positive fashion, and that this is seen by the general public to be the case. The creation of a ‘task force’ (involving all the main actors) charged with finding an integrated and sustainable solution for the entire Buenos Aires conurbation and satellite towns is required, which should also include representatives of civil society, water users and universities. The ‘who in-the-end pays’ question obviously has to be addressed and requires political decision.

Box C

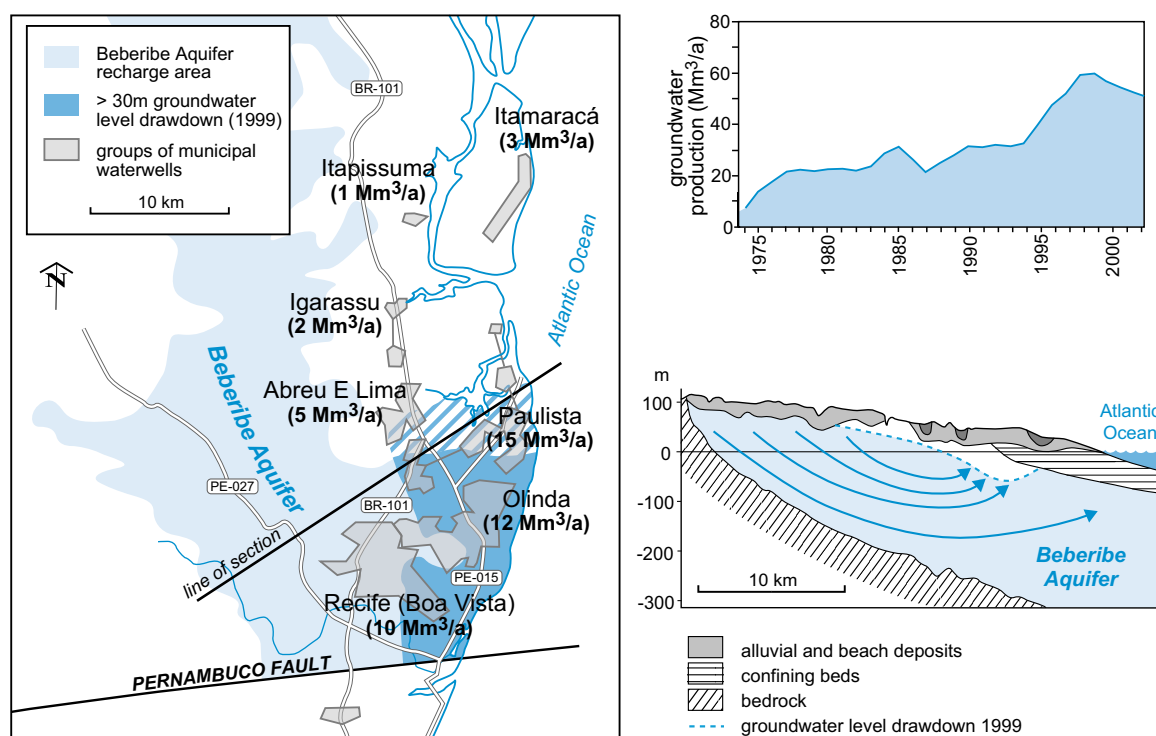
RECIFE - BRASIL

DEPLOYMENT OF BEBERIBE AQUIFER AS A KEY ELEMENT AND STRATEGIC RESERVE FOR MUNICIPAL WATER-SUPPLY

The rapidly-developing Recife Metropolitan Region (RMR), capital of the Brazilian State of Pernambuco, currently has a population of over 3.0 million and a maximum water demand approaching 15,000 l/s (including high 'non-accounted for' and physical leakage losses in total still exceeding 50%). It is situated in a humid tropical zone with about 2,000 mm/a rainfall (concentrated during April-July) and elevated temperatures. COMPESA (the state water-service utility) has progressively developed surface water sources in four separate systems to supply the RMR area, whose total capacity had reached over 8,000 l/s by 2008 but that reduced in severe drought to less than 3,000 l/s – with the projected Pirapama System providing up to an additional 5,000 l/s. The operation of these systems is such that only the Botafogo System (yielding 500-1600 l/s) can supply the suburb of Olinda and northwards (Figure C1).

Hydrogeologically the RMR is also divided into two main areas : RMR-Norte (Boa Vista, Olinda, Paulista, Abreu de Lima, etc) (Figure C1) and RMR Centro-Sul (Boa Viagem, Imbiribeira, Jaboatao, etc) by a major geological lineament, leading to sharply contrasting hydrogeological conditions and groundwater potential on either side. The main focus here is the Beberibe Aquifer of RMR-Norte, an Upper Cretaceous Sandstone of some 200m thickness dipping below younger strata as the coastline is approached (Figure C1). This is widely developed over 50 km along the 20 km-wide coastal strip north of Recife (providing typical waterwell specific capacities of 1-2 l/s/m drawdown) and is partly confined by an upper cemented calcareous facies and overlying argillaceous strata up to 20m thick.

Figure C1 : Hydrogeological conditions and evolution of groundwater production from the Beberibe Aquifer in the Recife Metropolitan Region



This is not to say that there is no groundwater use in RMR-Sul. In this area shallower groundwater is intensely exploited by some 6,000-8,000 private waterwells – mainly drilled in response to extreme municipal water shortages during the droughts of 1993-94 and 1999-2000 and still exploited (at an estimated rate of 2,000 l/s) as a low-cost supply-source for multi-residential properties and hotel facilities. Groundwater potential is much less, with high susceptibility to saline down-coning/ intrusion and vulnerability to anthropogenic pollution, and uncontrolled abstraction associated with very high rates (>500 lpd/person) of residential water use, has allegedly caused widespread aquifer degradation.

The Beberibe Aquifer of RMR-Norte has been used by COMPESA to provide mains water-supply for RMR-Norte since 1975, when 22 waterwells were brought into production to provide 690 l/s (Figure C1) – there having been a few pre-existing industrial waterwells in the aquifer (notably those of the Antarctica brewery in Olinda with a total yield of 300 l/s). The aquifer response with water-level drawdown locally to around -60 m MSL, gave cause for concern (Figure C1), although this was not accompanied by any rapid saline intrusion. But continued expansion of groundwater production by COMPESA occurred, especially in Paulista, and by 1985 had reached a total of 1,000 l/s (Figure C1). From 1987 development of the Botafogo System has provided a potential source of 1,600 l/s (which initially allowed the maximum rate of groundwater abstraction to be scaled back to 690 l/s), but this reduced to only 500 l/s in drought. Thus at various times during 1990-95 groundwater production was increased to 1,970 l/s (from 137 operating wells), although by 2002 peak production had been trimmed back to around 1,500 l/s (Figure C1). In addition it is estimated that private industrial waterwells in RMR-Norte are abstracting about 700 l/s – although the depth of aquifer productive horizons is such as to have largely prevented the phenomena of residential self-supply from groundwater.

In RMR-Norte SRH-PE (the state water planning authority) and COMPESA have adopted the strategy of utilizing the Beberibe Aquifer for the water-supply of outlying districts which were difficult to cover from other sources – but the replenishable resources of this aquifer are constrained by its geographical extension and it will be more rational to evolve to using its large groundwater storage as a strategic reserve for amplifying conjunctive use with surface water-supplies in RMR Centro/Norte, whose yield in drought will be much reduced. To realise this adaptive management strategy, which offers greater long-term water-supply security, the following lines of investigation and development will be required :

- hydrogeological investigation to identify any saline-water interfaces in the aquifer, the presence of any overlying patches of polluted or saline groundwater, the most probable aquifer recharge mechanisms and rates (including water-mains leakage) and the evidence for natural aquifer discharge both onshore and offshore
- a detailed survey and inventory of current industrial and commercial groundwater abstraction – including up-dating the administration status of their use permits and arriving at a reliable estimate for non-COMPESA groundwater abstraction and its seasonality
- a concerted programme of appropriate land-use control on the recharge area of the Beberibe Aquifer (Figure C1)
- an evaluation of the availability of surface water-sources to supply RMR-Centro/Norte within various time-frames, the seasonal variability of their yield and other vulnerabilities
- construction of a numerical aquifer model (using UFPE staff working closely with COMPESA), which should be calibrated in transient condition with historic groundwater abstraction and drawdown data, and the improved monitoring of current status – this model should be used primarily to inform dialogue about amplifying conjunctive use options through the evaluation of scenarios of increased drought abstraction.

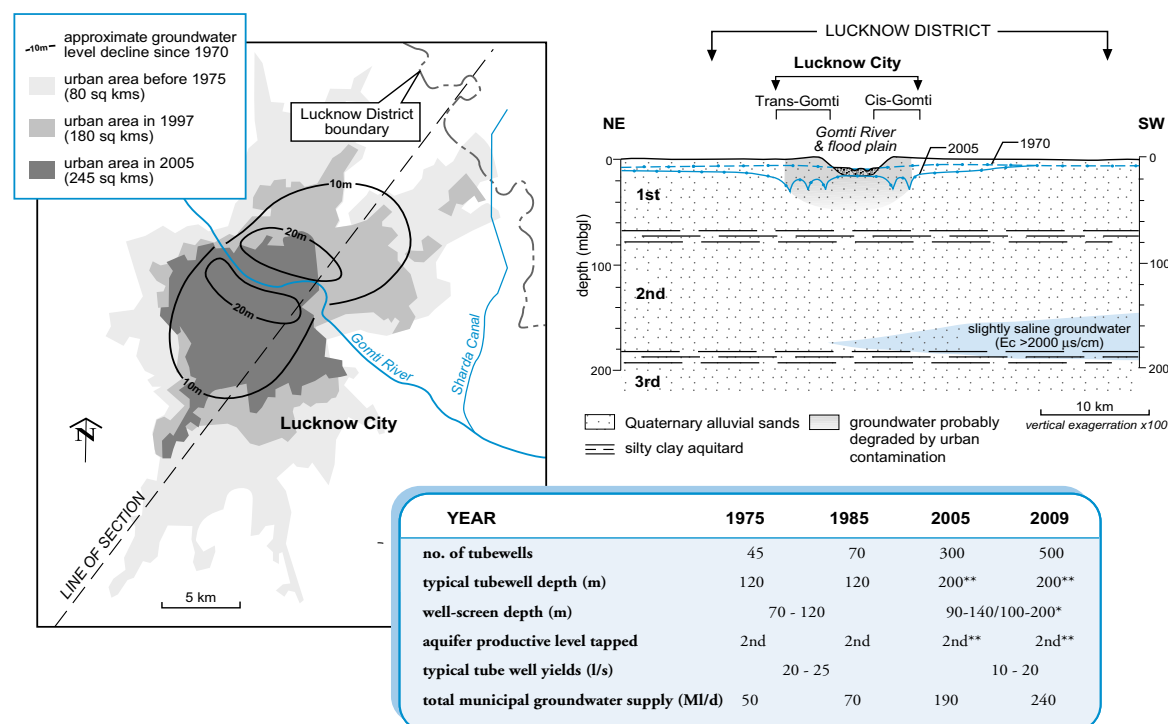
The Beberibe Aquifer of Recife is a good example of a high-yielding groundwater system close to a major urban area, whose geographical extension and regional flow is not sufficient for it to become a 'sole source' of urban water-supply, but whose freshwater storage reserves are large and need to be proactively protected and conjunctively managed to provide increased water-supply security at minimum possible cost.

Box D**LUCKNOW-INDIA****‘ALLUVIAL GROUNDWATER CITY’ REQUIRING IMPROVED RESOURCE UTILISATION AND PLANNED CONJUNCTIVE USE**

Lucknow City on the Central Ganga alluvial plain is underlain by a large thickness of Quaternary alluvial sands, with ‘three productive aquifer horizons’ down to 300m separated by occasional silty clay aquitards — there is occurrence of marginally-saline groundwater at 140-200 m depth across the ‘cis-Gomti’ (west bank) area (Figure B1). The climate is sub-tropical with an average rainfall of 1140 mm/a, the majority of which normally falls during the main monsoon months (June-September), but in some years the monsoon rains can be much reduced.

Since 1892 Lucknow has had a limited public water-supply network based on a small intake and treatment works on the Gomti River – but the population of Lucknow Metropolitan Area grew rapidly from 1.0 million in 1981 to 2.3 million in 2001, and is projected to reach 4.0 million by around 2020. Conjunctive use of groundwater and surface water commenced ‘incidentally’ from 1973, following construction of the first tubewells for the Lucknow municipal water-supply undertaking (LJS) tapping only the ‘second productive horizon’. In an effort to meet rapid urban growth and spiraling water-demand, over 300 municipal tubewells had been drilled with the more recent 200-350 m deep – and the gross municipal supply available by 2005 was 490 MI/d, of which around 240 MI/d is derived from groundwater and 250 MI/d from surface water, with the Gomti intake having been replaced (because of flow reduction and pollution) by an authorised offtake from Sardhar Irrigation Canal.

Figure B1 : Lucknow District – hydrogeological cross-section and growth in urbanized area and municipal groundwater use during 1975-2009



* differences between cis-Gomti and trans-Gomti areas because of occurrence of slightly saline groundwater
 ** some tubewells drilled to 350m depth to tap 3rd productive aquifer horizon

In the 1950s, pre-monsoon water-table depths were mainly less than 10 m bgl, but today they have been widely depressed to below 20 m bgl, have passed 30 m bgl in some areas and continue to decline at rates in excess of 1.0 m/a. In consequence tubewell yields have reduced significantly, because of the highly localised concentration and continuous use of tubewells rather than an overall resource deficiency in the aquifer system. However, all LJS tubewells deliver raw water quality conforming with current Indian drinking water norms, although private tubewells tapping the 'first productive horizon' record elevated NO_3 concentrations (over 100 mg/l) whilst others have excess dissolved Fe and Mn suggesting a heavy DOC and N load from wastewater infiltration.

Today the LJS operational position can be summarised as follows :

- growth in urban demand and water-table decline has resulted in a 'major public works effort' to construct and commission 40 new tubewells per year and to recondition many others
- substantial physical leakage losses (estimated around 30% overall), especially from older sections of the distribution network, reducing deployable supply to about 345 MI/d
- source and distribution limitations, such that service is typically 6 hours/day at low pressure with individual use about 100 lpc/day, except in a few areas with better service and some outlying colonies dependent on water tankers.

Like most 'alluvial groundwater cities', Lucknow has a smaller differential between the economic cost of municipal supply (running costs of about US\$ 0.12/m³ – although current charging results in users paying just over US\$ 0.04/m³) and private in-situ tubewell water-supply (capital and running cost of US\$ 0.15-0.30/m³ – more expensive than in hard-rock aquifers because of more costly well construction). But in some areas there has recently been an increasing rate of private waterwell construction, in essence as a 'coping strategy' by those seeking (and prepared to pay more for) a secure continuous supply. However, the long-term availability of local groundwater resources remains good and the current problem is as much one of over localised abstraction and distribution system constraints than of absolute resource shortage.

Municipal water engineers tend to favour reducing dependence on groundwater (because of its operational complexity) and opting for a major new surface water transfer scheme. There are plans to augment further Sardhar Canal flows from the Upper Ghaghara Basin (150 km or so distant) in an attempt to guarantee the availability of 500 MI/d in all seasons at the city canal offtake – but such a scheme would be highly vulnerable to climate-change impacts (long-term baseflow reductions from the Himalayan mountain chain due to glacier recession) and agricultural sector competition (potential drought conflicts with the farming community across whose land the canal runs).

Moreover, the 2025 demand prediction for Lucknow City requires a gross available supply of 810 MI/d (before leakage losses are deducted), which would imply maintaining or even expanding local groundwater production. It is thus considered that the robust way to face the future urban water-supply challenge is to look towards a more integrated and harmonised conjunctive use of surface water and groundwater sources, including the development of rural protected wellfields within 20 km of Lucknow City (for example in areas which are experiencing soil water-logging as a result of high and/or rising water-table where there would be a secondary benefit of improving land drainage and crop productivity).

Box E**NATAL - BRASIL****A RAPIDLY-EXPANDING 'GROUNDWATER CITY' REQUIRING MORE INTEGRATED LAND-USE AND WATER-SUPPLY PLANNING AT METROPOLITAN LEVEL**

The rapidly-developing Natal Metropolitan Area in Rio Grande do Norte State comprises 9 semi-independent municipalities of about 1.2 million population total with Natal Municipality at its centre. It is spread out along the Atlantic coast mainly on the Barreiras Aquifer System (Figure D1), comprising up to 70m of consolidated aeolian strata (overlain locally by 30 m of recent dunes) which yield 15-30 l/s to waterwells. Natal Municipality area is extensively urbanised, except for some ecological dune reserves, and CAERN (the state water-service utility) supply 95% of the 0.8 million population, but only 35% have a mains sewerage connection with the rest depending upon in-situ sanitation. In general terms the entire area is under great urbanization pressure, but there are some areas around intra-dune lagoons along the coastline, which for their ecological merit enjoy protection against indiscriminate development.

In 2006 the total number of registered waterwells was 1480 and these were estimated to be producing 16 Mm³/a of private water-supplies and 50 Mm³/a to the municipal public water-supply system, which was supplemented by 37 Mm³/a from two groundwater-linked lagoons (Lagoa de Extremoz and Lagoa de Jiqui – Figure D2) to the north and south of the Metropolitan Area which is divided by the Potengi river estuary. In addition CAERN has developed a wellfield by the Lagoa do Bonfim (Figure D1), at the southern extreme of the Metropolitan Area, to supply a very long aqueduct for small towns in the interior, which produced 6 Mm³/a in 2008 with a projected expansion to over 10 Mm³/a in the coming years.

Rainfall is relatively high (averaging 1690 mm/a) with seasonal distribution (February-May) and infiltration under natural vegetation occurs at rates of 410 mm/a – but on average this is believed to increase to about 600 mm/a in urbanized areas as a result of water-mains leakage (30% of 315 lpd/cap – a high rate of gross supply) and wastewater infiltration, despite the reduction in soil infiltration due to land-surface impermeabilisation. The current rate of groundwater resource abstraction is, by comparison, equivalent to 430 mm/a over the 'municipal area'.

Figure D1 : Hydrogeological cross-sections of Natal Metropolitan Area

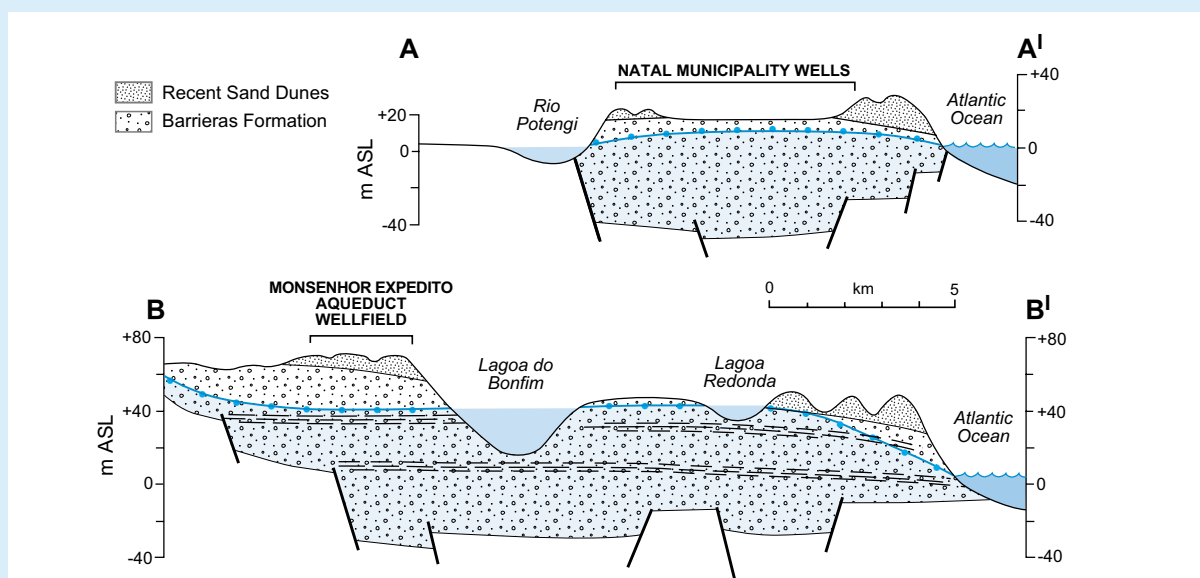
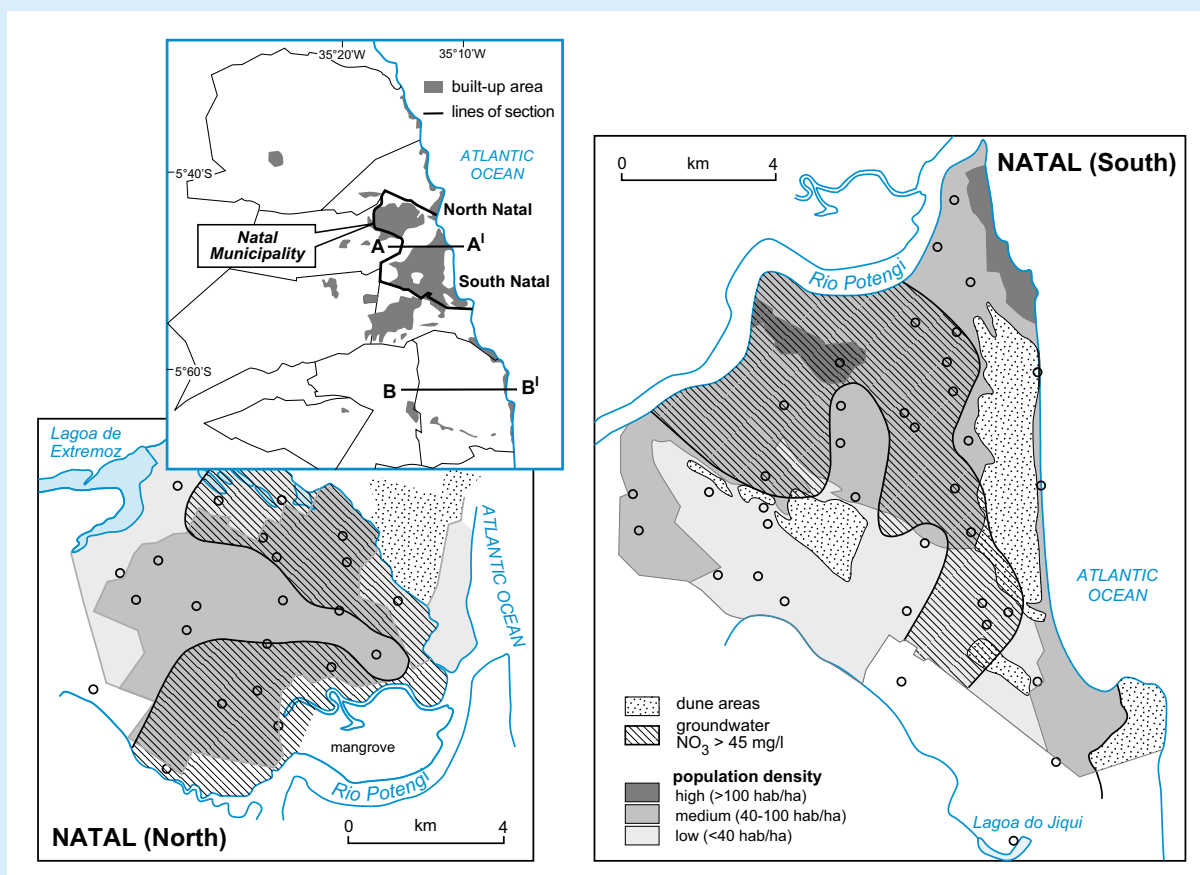


Figure D2 : Population densities and groundwater nitrate concentrations in Natal Metropolitan Area



The major issues currently facing groundwater use for 'municipal water-supply' are :

- a growing problem of nitrate pollution, such that now 70% and 60% of CAERN waterwells in Natal north and south respectively exceed the Brazilian drinking-water guideline concentration (45 mgNO₃/l) (Figure D2)
- a rapidly growing water-demand associated with accelerated population growth and increasing per capita use.

The former problem has been clearly correlated with the historical evolution of urbanisation served by in-situ (unsewered) sanitation. At present there is little evidence that (at the intake screen depth of CAERN waterwells) this is accompanied by other more dangerous types of pollution, although there is some risk of this occurring at least locally. Given the prohibitively high cost of nitrate removal, the problems are currently being solved by :

- dilution of high-nitrate groundwater from remote low-nitrate lagoons and waterwells
- abandonment of the most polluted waterwells and their replacement with new sources.

In the longer-term the following management measures need to be implemented :

- securing groundwater quality, where local conditions permit the introduction of source protection zones
- increased groundwater quality monitoring, especially in commercial and industrial areas, and control of potential sources of more hazardous groundwater pollution
- demand management via tariffs to constrain luxury uses
- prioritising sewerage sanitation in areas with relatively low groundwater nitrate concentrations
- water harvesting and recharge enhancement where appropriate urban conditions exist.

The successful implementation of a suite of such measures will be highly dependent upon much improved communication and cooperation between individual municipalities, so as to achieve full consideration of groundwater conditions and vulnerabilities, and integrated decision-making on land-use planning and wastewater management.

- **Pollution** – from urban in-situ sanitation deployed under high population densities and/or in vulnerable hydrogeological settings, with other forms of contaminant pressure from industrial and community chemicals (which, if they result in the need for advanced treatment or large-scale dilution greatly increase the operational cost for municipal water utilities) – **Box E** on Natal-Brasil is a good illustration of this type of problem.

Policy Development for Major Urban Aquifers

Improving Sustainability of Municipal Utility Use

- Groundwater use sustainability is greatly influenced by a complex array of local developmental decisions, which are rarely viewed in an integrated fashion, including :
 - production and distribution of water-supplies (by municipal water-service utilities and public-health departments)
 - urbanisation 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 and municipal water-service utilities).
- Municipal water-service utilities have tended to focus mainly on the engineering of waterwell construction and operation, and (with a few notable exceptions) have shown little interest in understanding and managing the resource base – thus the criteria for waterwell siting and construction usually relate solely to meeting immediate supply requirements at minimum cost and are not evaluated in terms of optimal use of groundwater resources. This must change to meet future urban water-supply challenges in an efficient way.
- The following policy actions are thus required to ensure physical sustainability of the groundwater resource base :
 - definition of areas with critical levels of resource exploitation as a basis for restricting further development
 - providing clear criteria by area for issuing of waterwell permits (in terms of safe separation and maximum pumping rates)
 - controlling municipal and private groundwater abstraction on the basis of defined areas – including the relocation of municipal waterwells, increased resource-use fees, and (even) closure of private waterwells where local conditions so merit.
 - monitoring and periodic evaluation of groundwater resource status, including the use of numerical aquifer models

Such an approach (along with other measures) has been successfully applied in Lima-Peru to stabilise the local aquifer (**GW•MATE Strategic Overview Series 2 – Conjunctive Use of Groundwater & Surface Water**).
- A much more integrated approach to urban water-supply, mains sewerage provision and land-use is required to avoid persistent and costly problems, where local aquifers are providing an important component of municipal water-supply. This must include consideration of groundwater sustainability and normally involve the following types of measure :
 - prioritising some recently urbanised areas for coverage by mains sewerage so as to protect their good quality groundwater from gradual degradation

- limiting density of new urbanisation with in-situ sanitation to contain potential nitrate contamination to a tolerable level
 - establishing municipal source protection and/or exclusion zones, especially around any municipal waterwells that are favourably located to take advantage of parkland or low-density housing areas
 - assessment of the sanitary protection standards of municipal waterwells and the risks of wellhead contamination, and how they can be reduced
 - undertaking groundwater pollution vulnerability mapping and hazard assessment, and being prepared to abandon some municipal waterwells where the contamination risk by toxic synthetic substances is very high
 - avoiding creation of polluting discharges in ‘upstream areas’ that could percolate compromising the groundwater quality of municipal waterwells.
- In cities with high dependence on groundwater it is usually a good idea to pursue all reasonable opportunities for aquifer recharge enhancement, variously through rainwater harvesting and infiltration from roofs and paved areas, and collection of flood runoff to recharge basins or ponds – taking the provisions to avoid groundwater pollution. Much incidental recharge is often occurring by infiltration from stormwater drains and soakaways, although these need to be properly designed and maintained to operate as recharge enhancement structures.
 - Such cities also widely encounter problems of increasing and/or elevated concentrations of ‘residual persistent urban contaminants’ (notably nitrate). The most cost-effective way of dealing with this type of problem for municipal water-supply is by dilution through mixing, which requires a secure and stable source of high-quality supply, such as that produced from a suitably-located and carefully-protected ‘external wellfield’.
 - The establishment of municipal wellfields outside cities, with their capture areas being declared as ecological or drinking-water protection zones, must be promoted as ‘best engineering practice’. But in the developing world their promotion often encounters administrative impediments related to fragmented powers of land-use and pollution control between the numerous municipalities that usually comprise ‘metropolitan areas’. Procedures and incentives need to be established for the groundwater resource interests of a given urban municipality to be assumed by a neighbouring rural municipality, such that adequate protection can be offered for the capture area of an ‘external municipal wellfield’ providing water-supply to the main urban area.
 - An important corollary that must be addressed concomitantly is making best use of the increasing wastewater resources being generated from urban areas without compromising groundwater quality in areas of potable use – this should be an integral part of overall urban water resource planning.

Promotion of Conjunctive Use for Water-Supply Security

- For most large cities, the long-term sustainable groundwater resource is limited by aquifer geographical extension. In many such cases it may prove more rational to use the (naturally large) groundwater storage of nearby aquifers as a strategic reserve for conjunctive use with surface water-sources (whose yield will often be vulnerable to marked drought reduction), rather than for the traditional use of groundwater for base-load municipal water-supply in selected districts. And this will be the best way to confront the challenge of climate-change adaptation.

- To develop such an adaptive water resource management policy, which offers much greater long-term water-supply security, the following lines of under-pinning investigation will usually be required :
 - hydrogeological investigation to establish most probable aquifer recharge mechanisms and rates (including water-mains leakage) and the evidence for natural aquifer discharge, the position of any saline-water interfaces and potential presence of overlying patches of polluted or saline groundwater
 - detailed survey and inventory of current municipal, industrial and commercial groundwater abstraction from the aquifer system (including up-dating the administration status of their use rights and the socioeconomic profile of users)
 - assessment of the level of investment required to provide fuller interconnectivity within the municipal water-supply to allow most areas to be supplied for different sources
 - evaluation of the availability of surface water-sources for municipal water-supply within various time-frames, the seasonal variability of their yield and other vulnerabilities
 - construction of a numerical aquifer model (in transient condition), calibrated with historic groundwater abstraction and drawdown data – this model should be used primarily to inform dialogue about conjunctive use options through the evaluation of various scenarios of increased rates of abstraction during extended drought.
- Most conjunctive use presently encountered in the developing world amounts to a ‘piecemeal coping strategy’ in which:
 - waterwells have been drilled by municipal water utilities on an ad-hoc basis in newly-constructed suburbs to meet their water demand at the lowest possible capital cost (independent of the overall water-supply system)
 - surface water has been recently imported from a major new distant source to replace or reduce dependency on waterwells because of over-abstraction or pollution fears (**Box C**).
- However, there are examples of more integrated and optimised schemes, where the key to full development of conjunctive use has not simply related to source development but also to engineering of a mains-water distribution system that allows the majority of urban users to be supplied from different sources at different times (**GW•MATE Strategic Overview Series No. 2 – Conjunctive Use of Groundwater & Surface Water**). But it will often be necessary to promote a conjunctive use culture within municipal water utilities, since it runs contrary to some present cost-cutting axioms of water-supply engineering practice – it being necessary to encourage a more balanced view between long-term water source characteristics, limitations and reliabilities, and more narrow short-term considerations of operational efficiency and cost.
- The most common impediment to conjunctive use for urban water-supply is the fact that urban engineers water (usually pressed by day-today problems that require urgent attention) are forced to look for operationally-simple set-ups, such as a major surface water-source and large treatment works, rather than more secure and robust conjunctive use solutions. In some cases, vested interests in construction of more capital-intensive works also play a role. Such impediments need to be confronted both through capacity building and by state or provincial water resource agencies engaging closely with municipal authorities to look for technically sound and administratively reasonable solutions in the long-term interest of urban water-supply security.

- Given the numerous uncertainties and continuously evolving groundwater conditions in urban areas it is wise for an ‘adaptive approach’ to groundwater resource management to be adopted – this should be based upon continuous monitoring of groundwater levels and quality trends, and guided by transient numerical aquifer modelling. This will permit the evaluation of future groundwater abstraction scenarios, and lead to the definition of more robust and sustainable solutions to municipal water-supply.

GROUNDWATER USE FOR IN-SITU PRIVATE SELF-SUPPLY

Appraising Benefits & Risks of Private Use

- In-situ private self-supply from groundwater is mainly practised by urban dwellers who have sufficient financial resources (individually or communally) to act unilaterally to secure a more reliable water-supply – and can represent a significant proportion of the total water-supply – and in such situations its presence becomes of major significance to municipal water utilities since it :
 - reduces pressure on their (often limited) resource base
 - can meet demands whose location or temporal peaks present difficulty for mains water-supply.
- The initial private capital investment in self-supply is usually triggered during periods of partial failure or highly inadequate municipal water-supply service – essentially as a ‘coping strategy’ – the city of Aurangabad-India providing a graphic example of this circumstance (**Box F**). Continued private groundwater use by part of the population after improvement of the municipal water-supply (and sometimes the initial investment also) represents a ‘cost-reduction strategy’ – since the perceived unit cost of groundwater from private waterwells is lower than the applicable municipal water-supply tariff. However, electrical energy costs and quality considerations are not normally fully understood and taken into account – thus private users may not factor in all relevant costs potentially affecting their use.
- Unquestionably a key driver of private in-situ groundwater supply is the comparative cost with municipal water-supply – Fortaleza-Brasil (**Box G**) illustrates this situation well. In Brasil the charging system for multi-residential properties results in much of their water use being charged at a significantly higher tariff than the unit cost of private groundwater production.
- Intensive private groundwater use does not necessarily cause serious resource exploitation problems (such as saline intrusion or land subsidence), often because of abundant replenishment from water-mains leakage and in-situ sanitation seepage – but in various cases this will need further consideration.
- Whether private domestic groundwater use for potable supply presents a serious threat to the user himself will depend on the type of anthropogenic pollution or natural contamination present – with some pathogenic microbes, certain synthetic industrial chemicals and soluble arsenic and fluoride being the greatest concern.

Box F**AURANGABAD-INDIA****SOCIAL SIGNIFICANCE AND POLICY IMPLICATIONS OF PRIVATE IN-SITU GROUNDWATER USE IN A CITY OF THE INDIAN PENINSULAR**

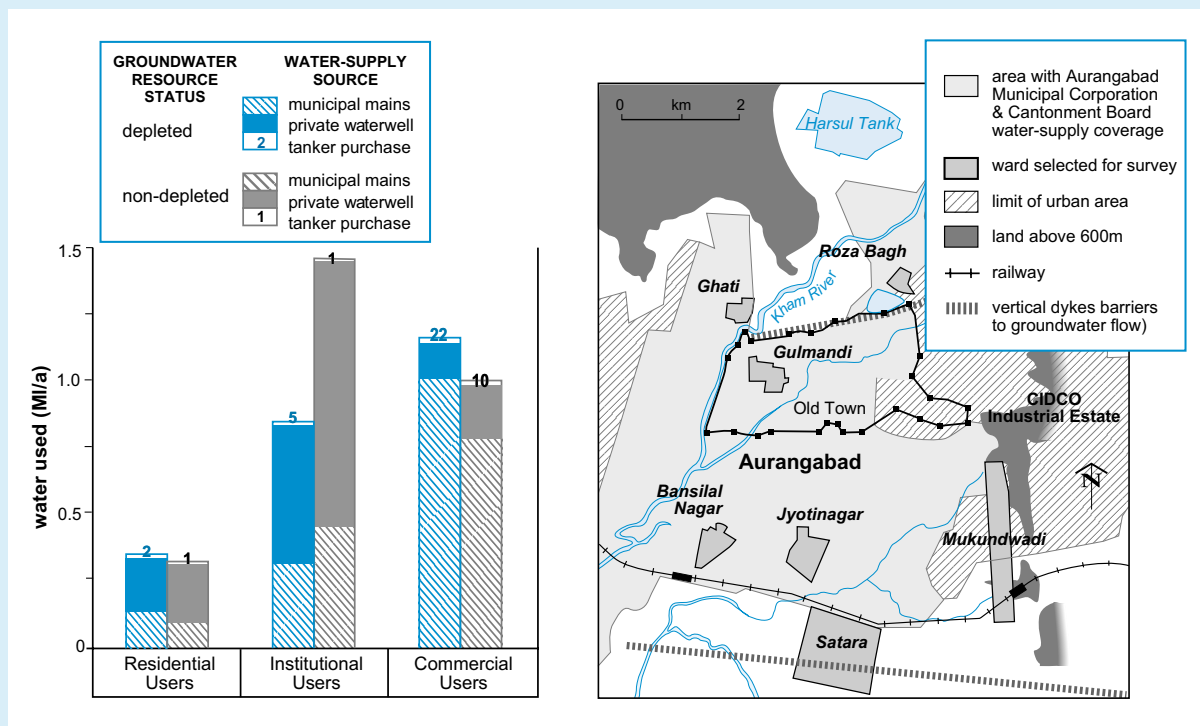
Aurangabad City, in the drought-prone interior of Maharashtra State, has grown rapidly over the last 20 years and now has an 'urban corporation area' of 138 km² and a population of 1.1 million. Responsibility for public water-supply was assumed by the Aurangabad Municipal Corporation (AMC) from state authorities in 1998. Prior to 1975 traditional sources ('nahars') delivered some 5-15 ML/d, but following the 1972 drought the authorities opted for a preferential supply from the Jayakwadi Reservoir (some 45 km distant and at 180 m lower elevation) rated at 28 ML/d in 1975, 56 ML/d in 1982, 100 ML/d in 1992 and 150 ML/d in 2005. Given electrical power shortages for high-lift pumping and limited storage in the urban distribution system, the service level of AMC water-supply is very poor (widely less than 1-in-24 hours), resulting in most residential properties and many commercial/institutional water-users drilling private borewells and/or purchasing tankered water to supplement AMC supply. However physical leakage losses in the AMC water-supply network are small because of very low distribution pressures.

Aurangabad has only limited groundwater resources – both in terms of resource availability and waterwell yield potential. It is underlain by Deccan Traps basalt lava-flows, with groundwater confined to the weathered horizon and generally moving southwest along the Kham river-valley. Post-monsoon groundwater levels are around 6m bgl but fall to below 10m bgl during the dry season, and locally have reached 30m bgl (with the weathered zone completely dewatered) by heavy pumping. Groundwater development mainly uses borewells equipped with small (0.5-1.0 bhp) pumps, together with and over 600 (mainly hand-pump) AMC waterwells to supplement its supply. A systematic field-survey of private groundwater use in representative electoral wards was conducted in 2007-08. The level of residential use increases markedly each year during February-April (depending on area) and reaches a maximum (20-50% higher) in May-June. Purchasing water from tanker operators has long been common practice, but the use of private borewells has reduced volumetric dependence greatly (Figure E1) – although the majority of residential users still have to purchase tanker-water for some weeks per year, (because of seasonal borewell yield failure). The data collected allow estimation of the quantities of water used by different stakeholders – with the average household consumption being in the range 0.32-0.35 ML/a (equivalent to around 200 lpd/person) a large proportion of which in volume terms is groundwater.

The capital cost of waterwell construction is very low (averaging less than US\$ 400) – but even so the associated private investment across Aurangabad City amounts to US\$ 1.4-2.2 million per ward. The main operating expenditure for groundwater users is electrical energy for pumping, (US\$ 11-67/month on electricity according to season). A review of recurrent expenditure reveals private groundwater costing US\$ 0.15 to 0.24/m³ as compared to tanker water at around US\$ 1.33/m³. The highly-subsidised municipal piped-supply (based on a fixed annual domestic charge) costs the equivalent of US\$ 0.03/m³, although AMC incurs operation and maintenance costs of US\$ 0.16/m³ (compatible with that of private groundwater use). The choice of residential users to drill private (or community) borewells is essentially independent of the level of groundwater availability – and is primarily a 'coping strategy' driven by the inability of the municipal water-supply utility to meet their requirements and the fact that shallow waterwells (even if only of limited yield) are now of relatively low-cost and provide a much more economical source of supply than that from water tankers.

Since 2004 AMC have been considering a scheme to increase the imported water-supply to 325 ML/d, but the required investment (of US \$ 80 million) is large and the scheme would also have high recurrent costs – raising serious doubts about cost recovery and financial viability. Anticipating the need to raise much increased revenue the AMC has been trying, against popular resistance, to introduce volumetric charging – clearly the widely established private access to groundwater will act as a serious constraint to future AMC cost recovery.

Figure E1: Average annual water use by different user categories in Aurangabad City



Aurangabad has some main collector sewers, but the system is malfunctioning and in consequence many properties discharge wastewater untreated to the extensive pluvial (monsoon) drainage network connected to natural channels feeding the Kham River – but it not clear to what extent this is benefiting groundwater recharge and/or prejudicing quality. The question of groundwater quality hazard associated with inadequate sanitary completion of urban waterwells and/or more generalised urban groundwater pollution will have to be systematically evaluated, but there is also equally serious concern that the microbiological quality of municipal water-supply may be seriously compromised as a result of low pressure and intermittent flow, and that water-tanker supplies are also not subjected to sanitary control.

Planning future water-supply in Aurangabad (and many similar cities of peninsular India) should not ignore the role of private self-supply from groundwater, and the following policy recommendations arise :

- access to groundwater will unquestionably affect the 'willingness to pay' for improved municipal supply of residential users and thus the viability of major new 'imported' water-supply schemes
- when planning future mains sewerage improvements the prevalent use and operational cost of groundwater from private waterwells should be taken carefully into consideration
- in evaluating the benefits and risks of in-situ groundwater use, microbiological and chemical quality should be a factor taken into consideration and appropriate advice provided
- the use of urban groundwater is in certain ways logical, especially for meeting the demand for sanitary and laundry purposes, where a more expensive treated water-supply may not be justified
- municipal authorities should provide further fiscal incentive and technical guidance to promote private action on roof and pavement water harvesting for aquifer recharge enhancement and for the reduction of groundwater pollution risk from wastewater disposal and hazardous substances.

But there remains an institutional vacuum in India when it comes to urban groundwater resource use, which needs to be filled if realistic and robust policy implementation is to occur – thus in Aurangabad a 'standing committee on groundwater' drawn from the AMC and relevant state government departments and agencies should be formed to formulate policy on private groundwater use.

Box G

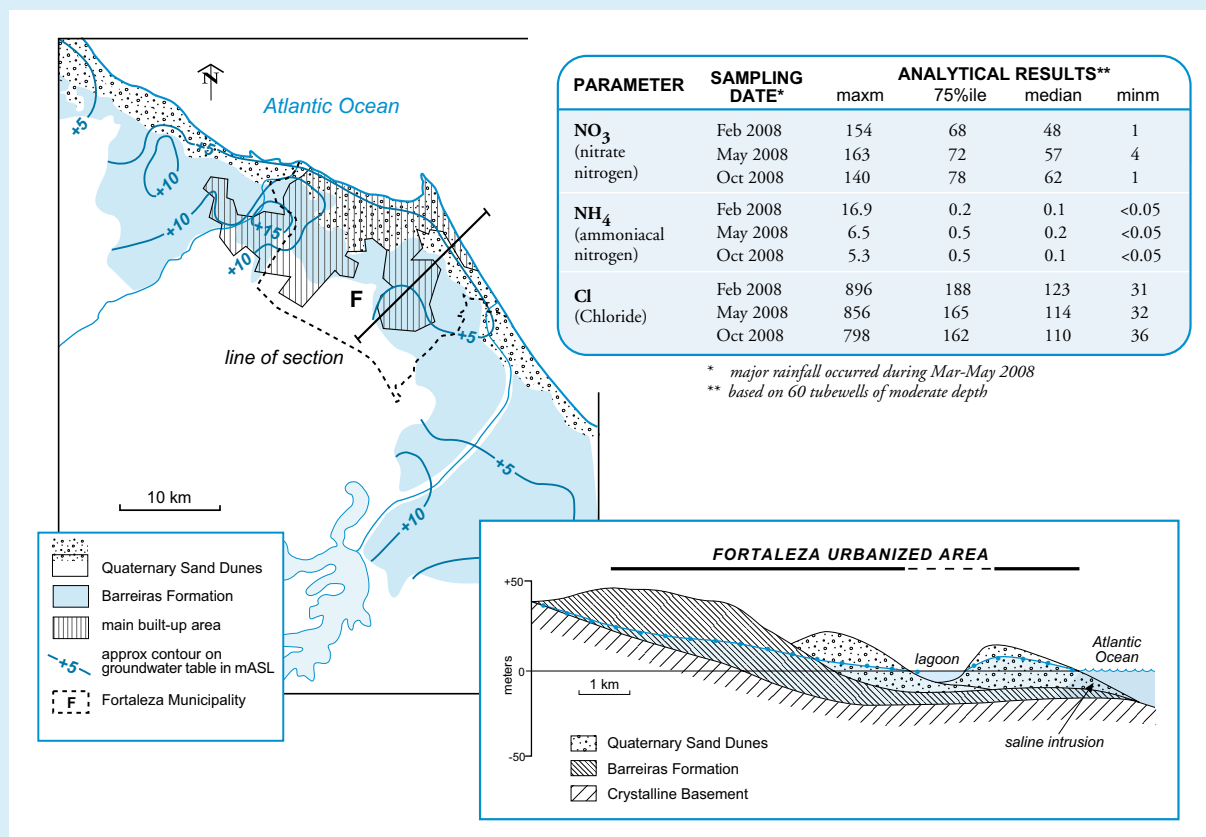
FORTALEZA - BRASIL

THE EVOLUTION AND SIGNIFICANCE OF PRIVATE IN-SITU GROUNDWATER USE FOR RESIDENTIAL WATER-SUPPLY

The Fortaleza Metropolitan Area is a coastal city, which includes 13 municipalities with a total area of 4,970 km², and has a current population of 3.0 million growing at 3.5%/a. Amongst these, Fortaleza Municipality (2.1 million) is a virtually-continuous urbanized area (except for an 'ecological park') (Figure F1), which has population densities in the range 20-70/ha and a very high degree (over 60%) of surface impermeabilization. The coastal strip is underlain by a laterally-variable aquifer system (mainly of aeolian and fluvial deposits) widely of 30 m or more saturated thickness, comprising the Tertiary Barreiras Formation (consolidated sands) overlain by Quaternary dune sands (expressed topographically by hills of 25-50 m height) (Figure F1). The area has a humid tropical climate which is markedly drought-prone – with a highly-variable average rainfall of 800-1,200 mm/a according to aspect (90% falling during February-May) but in dry years reducing to less than 25% of average.

Aquifer replenishment takes place by a variety of mechanisms including diffuse recharge of excess rainfall (reducing due to land surface impermeabilization), infiltration of surface water runoff from the interior along riverbeds and in lagoons, leakage of water mains (varying with extension of mains coverage and campaigns to reduce leakage, but more than 15% of supply at present) and ground discharge of wastewater from septic-tanks and cesspits in areas without main sewers (reducing with extension of sewerage cover from 10% in 1990 to 50% in 2004). The groundwater flow regime is not yet defined in detail, but the water-table is in the range 2-15 m bgl and the aquifer system is locally susceptible to sea-water intrusion and everywhere vulnerable to pollution.

Figure F1 : Hydrogeological setting and groundwater quality in Fortaleza Metropolitan Area



CAGECE (the autonomous water-service utility) supply some 60-70% of the population from reservoirs, canals and treatment plants which have a 'guaranteed yield' of 570 Ml/d. While this may still not be sufficient to meet peak demand, availability is increasing markedly with completion of major 'canal transfer schemes'. Earlier periods of near collapse of the mains water-supply system during extended drought (most recently 1998), led to some 40-60% of the population (especially multi-residential properties) constructing waterwells for direct self-supply. Commercial and industrial groundwater users are also important – with major use for laundry installations and sports facilities.

The groundwater use survey in 2002-03 inventorized 8,950 fully-equipped waterwells (compared to about 1,700 in 1980) although it is suspected nearer 12,000 exist, – 85% are used for domestic water-supply and 80% are tubewells of 20+ m depth. The survey concluded that:

- the value of sunk capital in private waterwells is at least US\$ 19 million, and probably more than US\$ 25 million if an allowance is made for non-operative and non-inventorized wells
- potential groundwater production capacity in Metropolitan Fortaleza is about 200 Ml/d representing 36% of total drought water-supply provision, although this has only been realized in past years of extreme drought, and actual current use is probably about 80 Ml/d (less than 15% of the total)
- CAGECE use is restricted to supplying some 'outer municipalities' and is insignificant compared to that of the increasing number of multi-residential properties, commercial and industrial users – with more than 1,500 waterwells yielding more than 2 m³/hr (0.5 l/s) and being effectively outside the law (only 26 permits held on State Government register)
- the current abstraction of groundwater does not tax resources or lead to widespread coastal saline intrusion, since it is more than balanced by mains water leakage and wastewater infiltration.

Significant domestic usage of groundwater (especially by multi-residential properties in high-income areas) arises as a result of consumers avoiding use of mains water-supply at prices above the highly-subsidized 'family social tariff' (equivalent to US\$ 0.26/m³ – compared to actual CAGECE production costs of US\$ 0.40-0.50/m³ and the non-subsidized tariff of US\$ 0.75/m³). This could have major financial implications for CAGECE in terms of loss of revenue from potential water sales, difficulties of increasing average tariffs and resistance to recovering sewer-use charges from those operating private wells for the bulk of their supply – although CAGECE recently introduced a 'sewer-use charge' based on estimated domestic wastewater generation in properties with equipped waterwells. The state water resource secretariat and agency need to promote a policy which strikes a balance between the benefits and risks of domestic self-supply. For example it may be preferable to encourage groundwater utilisation for 'non-sensitive' uses such as garden watering, laundry processes, car washing, cooling systems, etc with provision of advice on appropriate plumbing arrangements for 'dual supply' – and reserve high-quality mains water for providing a basic potable supply to a larger number of consumers.

An important question of groundwater quality hazard arises, especially where the possibility of potable use is implied. The general picture emerging is that groundwater quality is controlled by the interaction of three main components :

- high quality natural recharge during the wet season
- equally high-quality water-mains leakage on a continuous basis
- leaching of N and DOC compounds during the wet season from the unsaturated zone in areas of present (and recent past) in-situ sanitation.

While shallow dugwells in particular exhibit fecal contamination, deeper soundly-constructed tubewells are largely free of direct contamination – although they exhibit some 'residual nitrate contamination' (15-35 mg NO₃/l) and chloride concentrations of 100-150 mg/l (Figure F1), – although there are local 'hot spots' with NO₃ > 45 mg/l, NH₄ > 2 mg/l and Cl > 500 mg/l (above the Brazilian drinking water guideline values).

- Moreover, there are those who argue that, for the poorest in society, reliable access to any low-cost, parasite-free, water-supply is preferable to no water access at all (and to use of scarce financial resources on expensive tankered supplies) – and that advice on the possible use hazards and the provision of bottled drinking water is a sufficient public-health precaution.
- A broader assessment of private in-situ use is thus required by the ‘public administration’ to formulate a balanced policy (Table 2) – from which it will be evident that the incidence and weighting of factors involved will vary with hydrogeological setting, making policy formulation somewhat more complex.
- Where the municipal water-supply utility temporarily has ‘excess developed resources’ and is subject to commercial incentives (putting ‘financial considerations’ before ‘social service’), it may well try to market the substitution of main water-supply for private self-supply (to multi-residential properties, commercial and industrial users) rather than deploying its available surplus to improve water-supply to low-income areas – and this may distort a ‘rational policy dialogue’

Formulation of a Balanced Policy for Private Use

- The governing principles for the public administration in drawing-up a policy position on urban private residential self-supply from groundwater should be :
 - maximising the benefits of private investments whilst minimising the associated risks
 - legalising larger volume private waterwells, such as multi-residential properties, hotels, commercial and industrial use, and keeping an updated record of smaller users who at the current status of the aquifer do not require an abstraction permit.

Table 2 : A ‘public-administration overview’ of the pros and contras of private residential in-situ urban water-supply from groundwater

PROS	CONTRAS
<ul style="list-style-type: none"> • greatly improves access and reduces costs for some groups of users (but not generally for the poorest because without help they cannot afford the cost of waterwell construction except in very shallow water-table areas) • especially appropriate for ‘non quality-sensitive’ uses – could be stimulated in this regard to reduce pressure on stretched municipal water-supplies • reduces pressure on municipal water-utility supply and can be used to meet demands whose location or temporal peaks present difficulty • incidentally can recover a significant proportion of mains water-supply leakage 	<ul style="list-style-type: none"> • interactions with in-situ sanitation can cause public health hazard and could make any waterborne epidemic more difficult to control, and also potentially hazardous where serious natural groundwater contamination present • may encounter sustainability problems in cities or towns where principal aquifer is significantly confined and/or mains water-supply leakage is relatively low • can distort the technical and economic basis for municipal water utility water operations with major implications for utility finance, tariffs and investments

- A balanced risk assessment of current private waterwell use practices is a pre-requisite for policy development and this has various facets :
 - evaluation of the state of aquifer resources and risk of saline intrusion or continuous water-level decline and loss of access
 - appraisal of groundwater quality status – primarily the level and type of any aquifer pollution (or threat of pollution) and the risks associated with any natural groundwater contamination (such as arsenic or fluoride)
 - audit of sanitary construction standards of private waterwells and their mode of use – and implications in terms of health hazard.
- If the assessment indicates a high-level of risk to either groundwater resources and/or to groundwater users, the following actions could be decided as appropriate to local conditions :
 - use metering and charging (directly or indirectly) to serve as a constraint on the use of private waterwells
 - issuing of health warning and use advice to private waterwell operators – and in the most serious of pollution situations declaring the sources unsuitable for potable and sensitive uses.
- It will also be equally necessary for the public administration to undertake an independent assessment of the benefits of private groundwater use in terms of relieving pressure on municipal resources (especially for non-sensitive uses such as garden irrigation, laundry and cleaning, cooling systems, recreational facilities, etc) and also of guarding against the possibility of groundwater table rebound and associated urban drainage problems should groundwater abstraction radically reduce.
- A number of tools can and should be developed to reduce the risk associated with private investment in groundwater development :
 - maps of waterwell yield potential and reliability, depth to main aquifer horizons, static groundwater levels (as the partial control on pumping lift), groundwater pollution vulnerability and natural quality hazards
 - protocols for waterwell design, construction and operation, and design and operation of in-situ sanitation (septic tanks and improved latrines)
 - order-of-magnitude assessment of the status of groundwater resource abstraction, levels of sustainability and seriousness of risks associated with persistent excessive abstraction
 - guidelines on groundwater use precautions in relation to quality risks, and procedures for rainwater harvesting and aquifer recharge enhancement at individual urban plot level.

Regularising Private Residential Self-Supply

- The large majority of private urban waterwells unregulated or illegal. If this situation can be regularised, taking advantage of the advances in geographical positioning, data capture and storage systems, it will have a number of benefits :
 - urban groundwater users can receive sound information and advice relevant to their use (waterwell construction standards, pollution risks/alerts, use precautions, etc) and protected against the impacts of excessive total abstraction and/or inadequate well spacing

- the sanitary completion standards of waterwells can be improved and their potential interaction with in-situ sanitation units (latrine, cesspools and septic tanks) reduced
 - the public administration will be in possession of much better data on private use, which will in turn feed into more realistic groundwater resource assessments and more realistic municipal water-supply provision
 - public authorities could also undertake periodic water analysis as a service to legal urban groundwater users (who ideally in return would pay a modest annual 'water resource fee').
- The most forthright attempts to regularise the private use of urban groundwater have been in places (such as Recife & Fortaleza in Brasil), where the municipal utility has (understandably) argued for the levying of a volumetric water charge in respect of mains sewer use by private groundwater abstractors. This has resulted in municipal utilities drawing-up comprehensive inventories of private waterwells on multi-residential, commercial and industrial properties – in Fortaleza charging for sewer use on properties with private waterwells is by type/size of property but in Recife metering is being introduced for this purpose.
 - An important emerging policy question is under what circumstances the risks or inconveniences of private residential self-supply in the urban environment might justify an attempt to ban such use of groundwater. Historically 'urban groundwater use bans' have been necessarily introduced to address specific problems :
 - in 19th Century London, for individual faecally-contaminated communal waterwells to control and eliminate a major cholera outbreak
 - during the 1980s in Caribbean capitals with aquifers highly-vulnerable to faecal contamination (such as Nassau-Bahamas) as a precautionary measure to reduce the possibility of transmission of a continental-scale cholera epidemic
 - in Bangkok-Thailand during the 1990s to reduce groundwater abstraction from a highly-confined aquifer which was causing land subsidence in areas exposed to tidal flooding (**GW•MATE Case Profile No 20**).
 - More recently some interpretations of the Brasil-Lei Federal de Saneamento 11.445 (2008) would make all domestic urban groundwater use illegal (but in others only new waterwells in areas where main water-supply is freely available) – although the constitutionality of this law is being challenged by some States and it can be justly criticised because :
 - it is unrealistic and, in effect, unimplementable at present
 - if implemented literally it would impose intolerable strain on municipal water-supply of some cities
 - it does not represent good use of scarce water resources, including the recovery of physical mains leakage losses which can be very high
 - it runs the risk of promoting abandonment of groundwater pumping with water-table rebound (which in low-lying cities could imply major costs).

CONCLUDING DISCUSSION

Integrating Groundwater into Urban Water & Land Management

- Groundwater is widely far more significant in water-supply of developing cities and towns than is commonly appreciated and is also often the ‘invisible link’ between various facets of the urban infrastructure. Regretfully organisations concerned with urban water-supply and environmental management often have a poor understanding of groundwater – and this needs to be corrected.
- Groundwater is a fundamental component of the urban water cycle and there is always need for it to be integrated when making decisions on urban infrastructure planning and investment, whatever its use status (Table 3). But this is not as simple as it might at first appear, since widely there has been little recognition of the groundwater dimensions of urban water and land management.
- In most developing cities population growth precedes construction of mains sewerage and waste-water treatment facilities – and in the meantime shallow groundwater can become contaminated from inadequate in-situ sanitation. It may be years before the full extent of pollution becomes apparent, because contamination of large aquifers is a gradual and hidden process, and full remediation of entrenched problems may be prohibitively expensive. Thus it is critically important to recognise the incipient signs of groundwater pollution and put in place (now widely accessible) groundwater protection measures.
- There are basically two institutional approaches to protect groundwater quality: specific regulatory codes and planning & consultation (Table 4). But the implementation challenge for both is clearly more severe in the developing world because :
 - population growth is rapid and public awareness is relatively low
 - the legal codes for water and environmental regulation are in the process of evolution and may not receive consistent political backing.
- Perhaps the main challenge as regards groundwater quality protection is promoting the acceptance of differential municipal land management for important recharge areas in the interest of groundwater recharge quality. The impediments which have to be overcome include coping with the often fragmented responsibility for land-use control and providing incentives for rural municipalities to protect the wellfields of neighbouring metropolitan areas.

Filling the Institutional Vacuum

- Urban groundwater tends to affect everybody, but is often the responsibility of ‘no body’. Municipal, provincial/state and national governments must find the political will and the practical means (within a sound hydrogeological diagnostic) to :
 - constrain groundwater demand and limit groundwater abstraction by socio-economic and/or regulatory measures (providing alternative water supplies where necessary) so as to avoid aquifer depletion and degradation

Table 3 : Summary of major policy issues associated with urban groundwater

ISSUE	IMPLICATIONS
Municipal Water-Supply Benefits	groundwater use for municipal water-supply has many benefits (including capacity to phase investments with demand growth and high quality requiring minimal treatment) but it usually comes with a need for integrated planning of urban land-use, effluent discharges and solid-waste disposal to avoid insidious and near irreversible degradation by pollution
Protected Municipal Wellfields	since some degradation of groundwater quality in urban municipal waterwells due to persistent pollutants is likely, it is necessary in parallel to develop 'external wellfields' and declare their capture areas as 'protected zones' to guarantee that a proportion of the total resource is of high quality and available for dilution or substitution
Conjunctive Use with Surface Water	the rates of replenishment of aquifers may not be sufficient to meet the demands of larger cities sustainably and in this situation it is preferable to use available groundwater resources and large storage reserves conjunctively with surface water sources – conserving groundwater for use during drought and other emergencies
Private In-Situ Use Benefits & Hazards	private in-situ use for urban residential, commercial and industrial water-supply can have significant benefits not only to the user but to the community (reducing demand on utility supplies, providing water in areas or volumes difficult for the mains network, not using high-quality mains water for garden irrigation and commercial/industrial cooling) and these benefits need to be valued in terms of the marginal cost of providing a volumetrically-equivalent alternative water-supply – but poorly-constructed and shallow urban waterwells can present a significant health hazard due to faecal contamination (in serious waterborne disease outbreaks) or chemical contamination (especially in areas without mains sewerage)
Water-Sector Financial Considerations	widespread self-supply can have major financial implications for water-service utilities, in terms of loss of revenue from potential water sales, difficulties of increasing average tariffs and recovering sewer-use charges from those operating private waterwells
Future Drainage Problems	should abstraction radically diminish (due to an increased offer of subsidised mains water-supply or to quality deterioration or pollution rumours) then groundwater levels will rise progressively to higher than the pre-urbanisation condition, potentially with serious sanitary problems and infrastructure damage in lower-lying areas

- encourage the spread of groundwater abstraction for metropolitan area or municipal water-supply over larger areas, facilitating the protection of wellfield investments through declaration of special protection areas
 - plan urban sanitation, regulate the storage of industrial chemicals and the handling of industrial effluents adequately to afford much improved protection of groundwater quality.
- In pursuing policy needs it will be essential to make a critical appraisal of the actual and preferred roles of national/state water-resource, environmental and economic planning agencies, municipal water-service utilities/companies, and municipal government offices (responsible for land-use decisions, pollution discharge licensing, etc), and avenues of consultation/communication between them. This will be necessary to overcome split institutional interests and responsibilities, and to establish a mechanism for long-term continuous review and action on urban groundwater issues.

Table 4 : Analysis of Possible Institutional Approaches to Groundwater Pollution Protection

MAIN OPTIONS	PLANNING CONSULTATION PROCESS	SPECIFIC REGULATORY CODE*
Procedure Involved	<ul style="list-style-type: none"> • WRA is 'statutory consultee' for all local government decisions and national ministry policies influencing urban, industrial and agricultural land-use, with opportunity to request modifications of (and exceptionally to veto) these to avoid/reduce potential groundwater quality degradation • to streamline this process WRA would normally provide maps based on APV assessment and SPA needs to indicate spatial variation in their concern and priority as regards groundwater 	<ul style="list-style-type: none"> • WRA has legal power and obligation to enforce groundwater quality conservation in priority areas • WRA would normally make preliminary delineation of proposed SPAs (and other vulnerable recharge zones) indicating their proposed land-use constraints – which would serve as basis for dialogue with all stakeholders and relevant local government departments, prior to field notices being posted to mark corresponding boundaries
Applicability & Advantages	<ul style="list-style-type: none"> • most hydrogeological conditions – since APV mapping universally applicable and APV zones normally 'predominate tool' used in formulating input to land-use planning (with parallel incorporation of SPA needs only where readily feasible) • provides scientific basis for rational graduation of land-use constraints and thus a balanced policy as regards groundwater quality protection 	<ul style="list-style-type: none"> • where public water-supply from groundwater is of major importance, aquifer is of high pollution vulnerability, recharge area is well defined and flow regime clearly delineated • more readily understood by land owners and by general public – and can readily become part of the overall local environmental conservation programme
Theoretical Limitations	<ul style="list-style-type: none"> • careful interpretation needed in layered multi-aquifer situations, so as not to be over precautionary • can prove difficult to cover risks associated with all potentially-polluting activities using general APV assessment 	<ul style="list-style-type: none"> • not readily adaptable to deep semi-confined aquifers nor extensive shallow low-lying alluvial aquifers, for which definition of 'source capture areas' (needing protection) is problematic and difficult for public comprehension
Practical Implementation Issues	<ul style="list-style-type: none"> • potential socio-political resistance because it can imply imposing land-use constraints over quite large areas, and provoke reduction of some land values and escalation of others • what to do about existing potentially-polluting activities and the extent to which these can be retrospectively modified to reduce groundwater quality hazard 	<ul style="list-style-type: none"> • smaller land areas generally involved thus land acquisition or financial compensation can be considered – but latter often administratively difficult and 'joint ecological land development' approach usually preferable • BMPs for agricultural activity may not be sufficient to provide level of groundwater quality protection required in highly vulnerable areas (and changes of crop type and cultivation regime or reduction of animal grazing densities often needed)

* could also be used to reinforce 'planning consultation process' in areas of priority concern for groundwater quality as a result of resource importance and/or pollution vulnerability

WRA water resources agency

APV aquifer (groundwater) pollution vulnerability

SPA (public water-supply) source protection area

BMP best management practice (for potentially-polluting activity concerned – which in most conditions would much reduce, but not completely eliminate, groundwater quality hazard)

- There are clear examples of places where action is being taken to fill the institutional vacuum and to remedy lack of concern or deficient coordination as regards urban groundwater :
 - Brasil – ANA (Agencia Nacional de Águas), with World Bank support, established in 2008 a national groundwater program to strengthen groundwater management at state-government level, including proactive consideration of urban groundwater use policy
 - India – a recent in-depth study by the World Bank for the MWR (Ministry of Water Resources) on pragmatic action to address groundwater overexploitation, recommended substantial strengthening of state groundwater management agencies, and one of their key roles would be the required institutional coordination for addressing urban groundwater problems (although in this case the question of powers on pollution control are not yet included)
 - Sub-Saharan Africa – a welcome initiative of SADC supported by the World Bank, is the establishment of a ‘Groundwater Management Institute of Southern Africa’, geared to practical approaches for groundwater management, including urban groundwater use and protection issues.

- However, these ‘top-down’ initiatives should be complemented with ‘bottom- up’ provisions. Mechanisms for groundwater stakeholder participation are usually much less defined in urban than in rural areas (where groups tend to nucleate around a common interest in groundwater use for irrigated agriculture or groundwater conservation to support dependent aquatic ecosystem). But the representation and engagement of major stakeholder groups will be an essential component of any ‘action plan’ for resource management and protection – thus there is a need to build social consensus.

- An effective Information & Communication System is required (see **GW•MATE SO-1 on Groundwater Governance**), which should provide not only fundamental technical information on resource status, trends and vulnerabilities, but also a guide to the complex network of public agencies, groundwater users and other stakeholders involved. An essential part of the communication challenge is a clear explanation of the consequences of ‘non-intervention’ – consideration must be given to the fact that :
 - groundwater pollution, once it has occurred, is very costly or impractical to reverse, and often eventually results in abandonment of municipal waterwells
 - replacement of lost groundwater supply assets usually entails high marginal cost and results in substantial increases in average municipal water-supply tariffs.

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