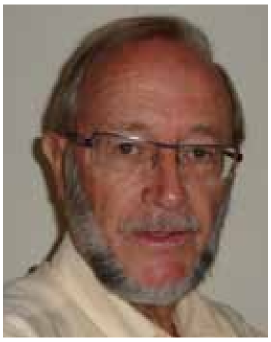

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GROUND WATER USE FOR URBAN DEVELOPMENT: ENHANCING BENEFITS AND REDUCING RISKS

Ground water is often a critical but unappreciated resource for urban development. This article analyses the benefits to the water-user community, the risks in terms of compromising resource sustainability and of the public-health hazard arising from urban pollution, and the implications as regards public water-utility investments. It is based primarily on World Bank Groundwater Advisory Team (GW-MATE) supported projects in Brazil, India and, more widely, in Latin America and Asia, together with preliminary information from a number of African cities. Key policy issues are identified, and appropriate institutional and management approaches to promote more rational and secure resource use are discussed.

Keywords: Urbanisation, urban water-supply, urban ground water resources, urban sanitation, conjunctive use

Urbanisation and ground water – the context

Modes and drivers of urban ground water use

Urbanisation has been the predominant global phenomenon of the 20th century and is predicted to continue at ever-increasing rates for the foreseeable future. Ground water has been a vital source of urban water-supply since the very first settlements – when it was captured at springheads and by shallow, manually excavated waterwells. In modern times the means of ground water capture have expanded to include deeper waterwells, with a major growth of urban ground water use in industrialised nations from the 1950s, and in the so-called 'developing world' from the 1980s. Today many countries exhibit a high level of dependence on ground water for urban water-supply (e.g. from Denmark and Germany to Brazil, Nigeria, Pakistan, Peru and Vietnam). The principal modes of ground water use in urban areas are summarised in Fig. 1.

To understand the dynamics of urban water-supply development and water-resource accounting it is important:

- To distinguish within utility use between waterwells constructed in urbanised areas (on a piecemeal basis in response to new demand centres) and protected 'external wellfields or springheads' (developed as part of a long-term water-supply strategy) (Foster *et al.*, 2010a).
- To appreciate that most utilities in the developing world (and some more widely) have high levels of 'unaccounted for' water (often more than 30 per cent and in some cases 50 per cent of the original supply), and that this includes a significant component of physical losses from the distribution system to ground water, in addition to illegal connections and other non-revenue losses.
- Not to overlook the potential significance of private self-supply from ground water, not just for industrial purposes (which is more traditional), but also by residential and commercial users.
- To recognise that any given urban area is in a continuous state of evolution on a time-scale of decades (Fig. 2) (Foster *et al.,* 1998).

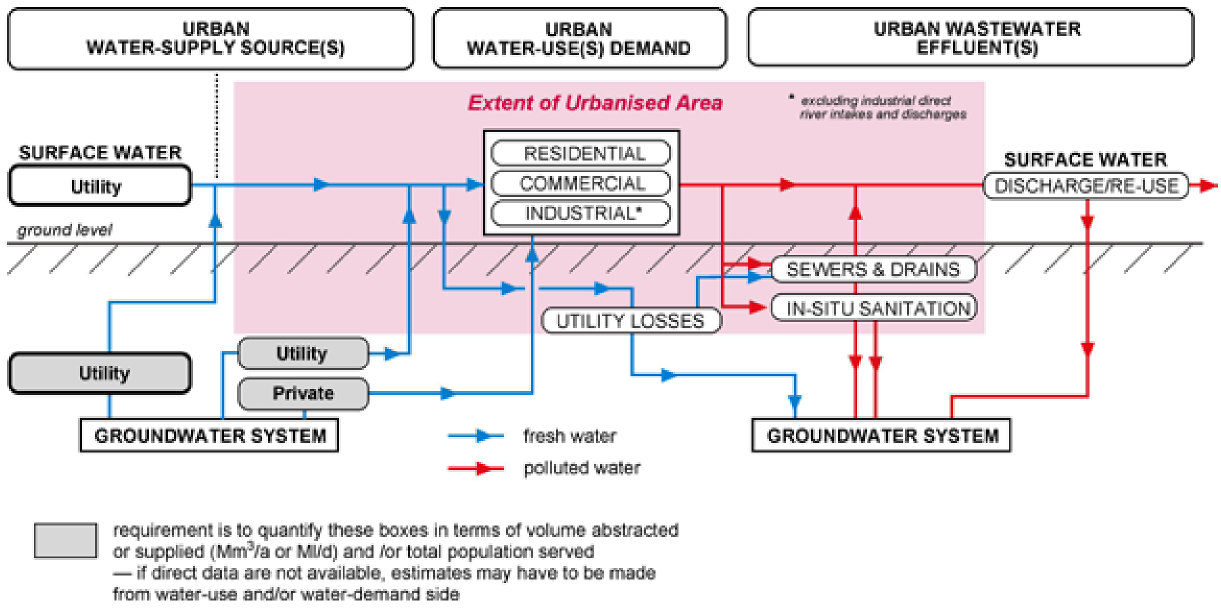

Figure 1. Sources and uses of urban water-supply and their generation of 'downstream' wastewater flows

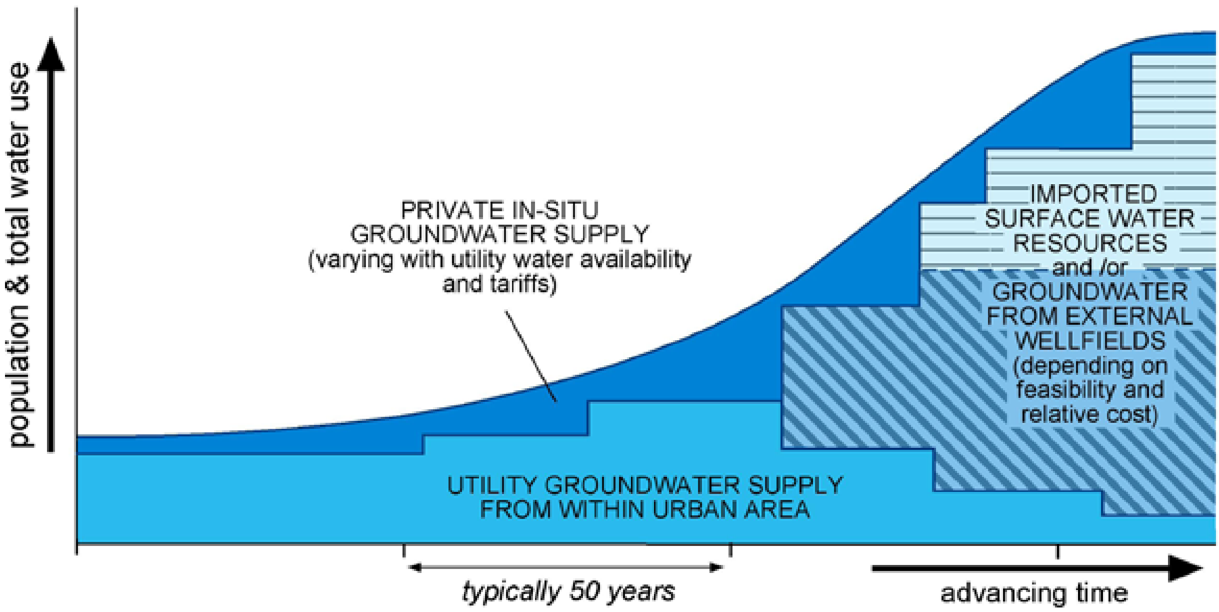

Figure 2. Typical temporal evolution of water-supply sources with large-scale urban development in areas surrounded by a high-yielding aquifer

Those urban centres surrounded by high-yielding aquifers (with sufficient potential to allow utilities to expand water-supply production incrementally in response to rising demand) usually have better mains water-service levels and lower water prices. While there are significant regional (and indeed local) variations in the evolution of urban water-supply provision and dependence upon ground water, the 'critical common factors' influencing use have been resource reliability for municipal supply and resource accessibility for private supply. Additionally, present-day drivers of urban ground water use include accelerating rates of urbanisation, increasing per capita water use, higher ambient temperatures and reduced river-intake security with climate change, and the generally low relative cost of waterwell construction (Foster *et al.*, 2010a).

In situations where the municipal water-supply service is (or has been) inadequate:

- Private operators sometimes develop local domestic water distribution systems (reticulated or tankered) based on water-wells (e.g. Asunción, Paraguay/Foster and Garduno, 2002).
- There is often a mushrooming of private in situ waterwell construction as a 'coping strategy' (e.g. Fortaleza, Brazil; Aurangabad and Bangalore, India) (Foster *et al.*, 2010a; Gronwall *et al.*, 2010).

Private supplies from ground water widely represent a significant proportion of the total urban water-supply 'actually received by users', and their presence has major implications for planning and investment in municipal water utilities. Although the 'economy of scale' can be poor, the cost of water-supply from this type of source often compares favourably with the tariffs implied by full cost-recovery from new utility surface water-supply schemes. The growth in private urban ground water use is not restricted to cities with ready access to high-yielding aquifers, but is often even more pronounced where minor shallow aquifers occur.

Ground water and the city – an intimate but fragile and neglected relationship

Urbanisation greatly modifies the 'ground water cycle' – with some benefits and numerous threats. The processes characteristic of urbanisation and industrialisation usually have a marked impact on aquifers underlying cities, and in turn man-made modifications in the ground water regime can have equally serious impacts on the urban infrastructure (Howard 2007; Foster *et al.*, 1998).

In general terms, urbanisation processes interact with ground water through:

- Substantially modifying, and generally increasing, ground water recharge rates through
  - The reduction in natural rainfall recharge through land-surface impermeabilisation usually being more than compensated for by physical water-mains leakage.
  - By infiltrating pluvial drainage.
  - By the 'return' of wastewater via in situ sanitation and leakage from faulty or ageing sewer systems.
- Greatly increased contaminant loading, as a result of
  - In situ sanitation and, to a lesser degree, sewer leakage and also inadequate storage and handling of 'community' and industrial chemicals.
  - Disposal of liquid effluents and solid wastes.

While in one sense ground water systems underlying cities represent 'the ultimate sink' for urban pollutants, the extent to which this applied subsurface contaminant load affects ground water will vary widely with the vulnerability of the aquifer system concerned.

Very rapid urbanisation, consequent upon large-scale migration of the rural population, is now occurring widely. This has lead to both escalating urban land prices from a construction industry boom and to major increases in the extension of informal unplanned slum dwellings. This is placing a heavy burden on municipal authorities for the expansion of the water-service infrastructure because it is 'by-passing' land-use planning and building regulations (e.g. Bangalore, India and Lusaka, Zambia) (Gronwall *et al.*, 2010). The latter, in turn, will frequently provoke ground water resource degradation and further complicate water-supply provision. Ways have to be found to get to grips with this situation.

Despite the frequent phenomenon of increased urban ground water recharge rates, there are rarely sufficient ground water resources within an urban area itself to satisfy the entire water-demand of larger cities. Other water-supply sources need to be introduced (Fig. 3). Otherwise, resource sustainability will become an issue (Foster *et al.*, 2010a; Foster *et al.*, 1998), and serious localised urban aquifer depletion (especially, but not only, in semi-confined systems) can result. This brings with it the risk of quasi-irreversible side-effects, such as induced seepage of contaminated water, land subsidence or coastal saline intrusion.

Later, in the evolution of major conurbations, there can be a 'sting-in-the-tail'. When pumping of ground water from the water wells in the central districts is abandoned there is a strong rebound in the water-table. (This results from the decline or migration of 'heavy industry', transformation from high-density residential to commercial use, ground water pollution fears, 'import' of major new water-supplies, etc.). This rebound can seriously consequences for established urban infrastructure, as illustrated by the experience of the past decades in Greater Buenos Aires, Argentina (Foster and Garduno, 2003).

Ground water resources near urban areas are thus influenced by a complex array of local development decisions, which are rarely viewed in an integrated fashion. These include:

- Authorisation of waterwell drilling and use (usually by water-resource agencies).
- Production and distribution of water-supplies (mainly by water-service utilities).
- 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 water-service utilities).

Pragmatic strategies for risk management

Improving the sustainability of municipal utility use

In the developing world it will be important for the future that ground water be used more widely on an efficient and sustainable basis for urban water-supply. It can often play a key role in water-utility adaptation strategies with regards to climate change. In this context it will be vital that:

- Effective demand management measures are introduced to constrain inefficient and unnecessary use, and reduce 'unaccounted for' water.
- The large ground water storage of most aquifers is managed strategically (in some cases as the 'last reserve') and used conjunctively with surface-water sources to improve water-supply security (Foster *et al.*, 2010b), rather than for base-load municipal water-supply (Fig. 4).

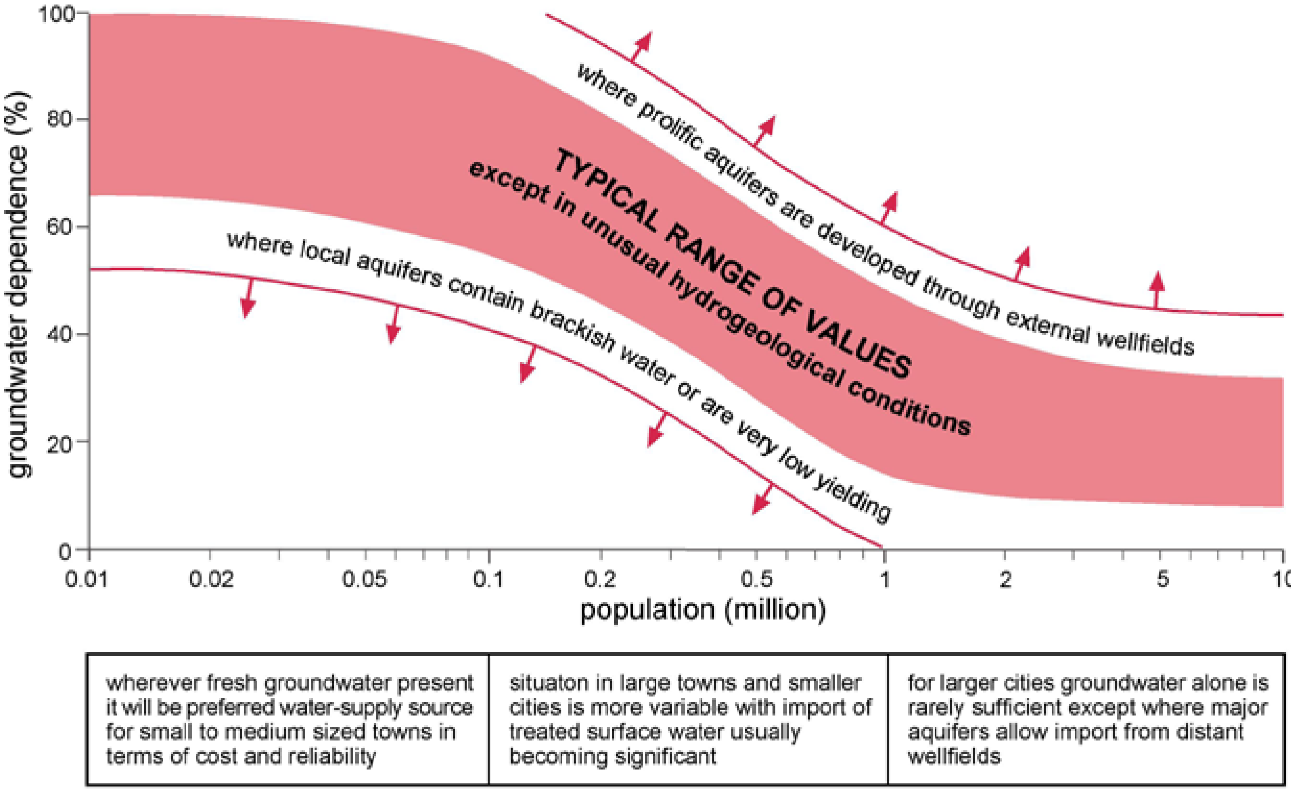

Figure 3. General relationship between ground water dependence for urban water-supply and the scale of urban development

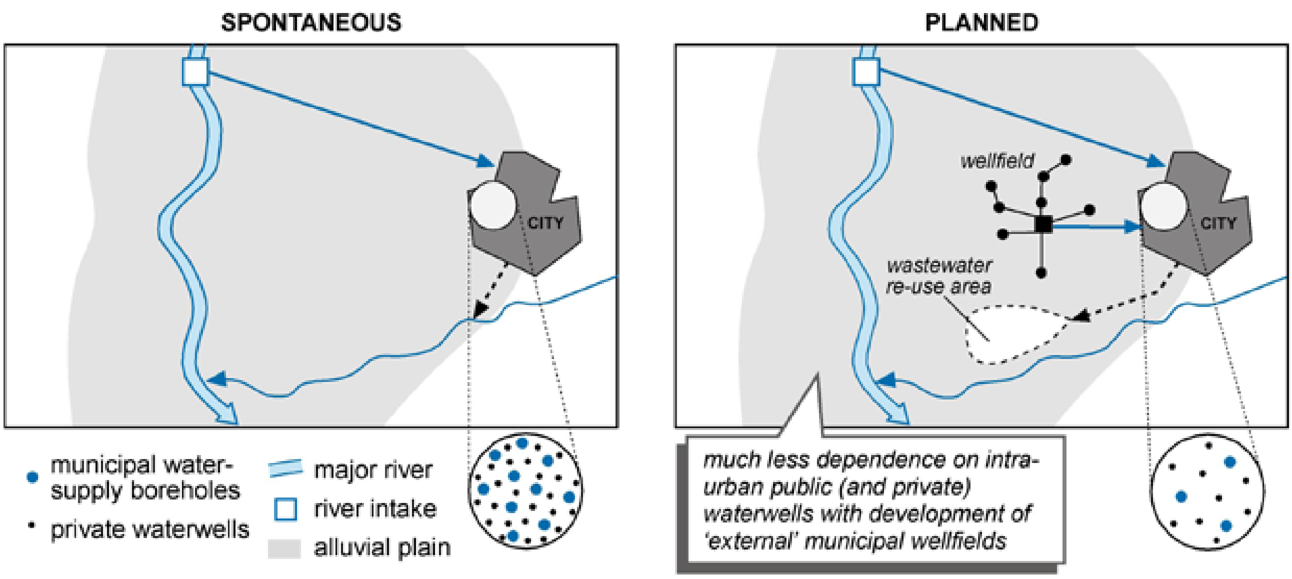

Figure 4. Schematic illustration of planned (as opposed to spontaneous) conjunctive use of ground water and surface-water sources for urban water-supply

But most conjunctive use presently encountered in the developing world amounts to a 'piecemeal coping strategy' (e.g. Lucknow, India) (Foster, 2010b) in which:

- Utility waterwells have been drilled ad hoc in newly constructed suburbs to meet their water demand at the lowest possible capital cost.
- Surface water has been recently imported from a major, new, distant source to reduce dependency on waterwells because of over-abstraction or pollution fears.

There are, however, a few examples of much more resource-optimised approaches (e.g. Lima, Peru and Bangkok, Thailand) (Foster *et al.*, 2010b). For more widespread promotion of such approaches a 'resource culture' needs to be generated with utilities. This may run contrary to some axioms of water-supply engineering that seek an operationally simple set-up (like a major surface water-source with large treatment works), rather than a more secure conjunctive resource management solution.

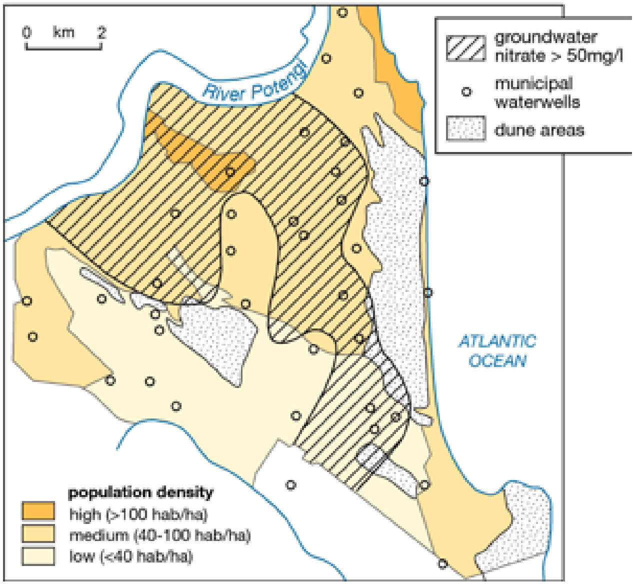

Figure 5. Excessive ground water nitrate concentrations in the coastal aeolian sand aquifer of Natal, Brazil (southern half) and their relation to population density. (The urbanised area is served by in situ sanitation except for a limited waterfront zone along the Potengi River)

Most importantly, establishment of utility wellfields outside cities (with capture areas declared as ecological or drinking-water protection zones) needs to be promoted as 'best engineering practice'. In the developing world it is either simply not considered at all or encounters administrative impediments related to fragmented powers of land-use and pollution control and between the numerous municipalities that comprise 'metropolitan areas' (Foster *et al.*, 2010a). Procedures and incentives need to be established for the ground water resource interests of a given urban municipality to be assumed by a neighbouring rural municipality. The procedures and incentives need to be such that adequate protection can be offered for the capture area of an 'external municipal wellfield' providing water-supply to the main urban area.

Given the continuous evolution of ground water use in 'urban aquifers', and the significant hydrogeologic uncertainty in predicting their precise behaviour, it is desirable to adopt an 'adaptive management approach' to urban ground water resources. This should be based on continuous monitoring of ground water levels and quality, and guided by a periodically updated, numerical aquifer model. This can also be used to evaluate future scenarios and for identifying the most suitable areas for 'external wellfield' construction.

Managing the sanitation-ground water nexus

The ground water sanitation nexus is especially relevant in developing nations, where in situ sanitation is much more extensive and presents a significant ground water quality hazard, which needs to be recognised and managed (Howard, 2007; Foster *et al.*, 1998). This threat is usually much more widespread than that posed by the inadequate handling of industrial chemicals and the disposal of industrial effluents.

In most aquifer types (except the most vulnerable and shallow) there will be sufficient natural ground water protection to eliminate faecal pathogens in percolating wastewater from in situ sanitation; these hazards increase markedly with sub-standard waterwell construction and/or informal or illegal sanitation and waste disposal practices (e.g. in numerous cities of Sub-Saharan Africa) (Foster, 2009). However, troublesome levels of nitrogen compounds (usually nitrate sometimes ammonium) and dissolved organic carbon in the ground water will also evolve to varying degrees, according to the population density served by in situ sanitation (Fig. 5). Such pollution can penetrate to considerable depths in the aquifer and persist after the contamination source is removed by the installation of mains sewerage or other alternative sanitation (Foster et al., 2010a). The most cost-effective way of dealing with this type of problem in municipal water-supplies is by dilution through mixing,. This requires a secure and stable source of high-quality water, such as that produced from protected 'external wellfields' (e.g. Natal, Brazil) (Foster *et al.*, 2010a).

In general, a much more integrated approach to urban water-supply, mains sewerage provision and urban land-use is required to improve the economic efficiency and security of urban water infrastructure. This improvement can be achieved, for example, by avoiding persistent and costly ground water quality problems (where local aquifers are providing a key component of municipal water-supply) that arise through piecemeal decision-making. There are numerous straightforward practical measures that can be taken by public administrations to improve the sustainability of urban ground water use. These include:

- Prioritisation of selected recently urbanised districts for mains sewer coverage to protect their good-quality ground water from gradual degradation. Also limit the density of new urbanisations served by in situ sanitation to contain ground water nitrate contamination.
- Establishment of ground water source protection zones around all utility waterwells that are favourably located to take advantage of parkland or low-density housing areas.
- Imposition of better controls for the handling and disposal of industrial effluents and solid wastes to reduce the risk of aquifer pollution.

Ground water pollution can also be reduced by deploying dry (eco-sanitation) units in which urine is separated from faeces and not discharged to the ground. However, while such installations are highly recommended for new urban areas overlying significant shallow ground water resources, their deployment as a universal solution to ground water contamination problems has limitations. Large-scale retro-installation in existing dwellings is not straightforward and it is less suitable for those cultural groups who use water for anal cleansing.

An important corollary that also needs to be addressed is how to make the best use of growing wastewater resources generated by increasing sewer coverage. This could be achieved through reuse for amenity and agricultural irrigation, which is spatially planned and appropriately controlled so as to minimise the risk of compromising ground water quality for potable use (Foster and Chilton, 2004).

Promoting rational private ground water use

The initial investment of private capital for in situ urban self-supply from ground water is usually triggered during periods of highly inadequate utility water-service or in the absence of such a service. This is essentially a 'coping strategy' (by multi-residential and individual properties, commercial and industrial enterprises). The well-researched Aurangabad, India example (Foster *et al.,* 2010a) reveals that all types of users tend to take water from multiple sources according to their availability and relative cost. These sources include subsidised water-utility mains supply, private and community in situ waterwells and, only as a last resort, much more expensive tankered water.

Private self-supply from ground water is widely practised by some users as a 'cost-reduction strategy' after the availability of utility supplies improves, The unit cost of ground water to private waterwell users is lower than the applicable municipal water-supply tariff (Foster *et al.*, 2010a) – albeit that many private waterwell operators do not consistently account for their running costs.

Intensive private ground water use alone (in the absence of large water-utility abstraction) does not necessarily cause serious resource overexploitation. Abundant aquifer replenishment from water-mains leakage and in situ sanitation seepage is often occurring. But whether private residential ground water use presents a serious threat to the user will depend on the type of anthropogenic pollution (or natural contamination) present,and the mode and type of water use concerned. Moreover, it can be argued that for the poorest in society, reliable access to any low-cost, parasite-free, water-supply is preferable to no water access at all (or to deploying scarce financial resources on expensive tankered supplies).

A broad assessment of urban waterwell-use practices is required by public administrations to formulate a balanced policy on private ground water resource use (Table 1).

If this assessment indicates serious hazards from ground water pollution or overexploitation, the following management actions could be considered (as appropriate to local conditions):

- Registering all commercial and industrial users, together with residential use for apartment blocks and other multi-occupancy housing estates and charging (directly by metering or indirectly by estimated sewer discharge) for abstraction, so as to constrain use
- Issuing water-quality use advice and/or health warnings to private waterwell operators. In severe pollution situations declaring sources unsuitable for potable and sensitive uses.

Equally, it will be necessary for the public administration to undertake an independent assessment of the benefits of private ground water use. This should help to relieve the pressure on municipal resources (especially for non-sensitive uses such as garden irrigation,

Table 1. A public-administration overview of the pros and cons of private residential in situ urban water-supply from ground water

Pros	Contras
• Greatly improves access and reduces costs for some groups of users (but generally not for the poorest because without help they cannot afford the cost of water well construction except in very shallow water-table areas)	• 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
• Especially appropriate for 'non quality-sensitive' uses– could be stimulated in this regard to reduce pressure on stretched municipal water-supplies	• May encounter sustainability problems in cities or towns where principal aquifer is significantly confined and/or main water-supply leakage is relatively low
• Reduces pressure on municipal water-utility supply and can be used to meet demands whose location or temporal peaks present difficulty	• Can distort the technical and economic basis for municipal water utility operations with major implications for utility finance tariffs and investments
• Incidentally can recover a significant proportion of main water-supply leakage	

laundry and cleaning, cooling systems, recreational facilities, etc.). It would also guard against the possibility of ground water table rebound and urban drainage problems should abstraction radically reduce. When large numbers of more affluent dwellers opt for in situ self-supply in urban areas, the knock-on effects are complex. It can, on the one hand, 'free up' utility water production capacity to meet the needs of more marginal low-income neighbourhoods. On the other hand it can 'reduce utility revenue collection', making it more difficult to maintain highly subsidised social tariffs for minimal use. And where a municipal water-utility has developed 'excess resources' and is subject to commercial incentives, it may market the substitution of mains water-supply for private self-supply, thereby distorting a 'rational policy dialogue'.

An important emerging policy question is under what circumstances the risks or inconveniences of private residential self-supply from ground water in the urban environment might justify an attempt to ban such practice completely (Foster *et al.,* 2011). Historically, 'urban private waterwell use bans' (or severe constraints) have been necessarily introduced as part of an effort to address:

- The control of a specific waterborne disease outbreak (e.g. cholera in 19th century London or in some Caribbean ports in the 1980s).
- Land subsidence and increased flood risk due to excessive ground water abstraction (e.g. Bangkok and Jakarta since the 1990s).

But they usually have high transaction costs and, alone, may only be partially successful. In Brazil, ground water abstraction constraints are currently imposed in specific zones of Ribeirão Preto and São José do Rio Preto (both in São Paulo State) to address problems of local overexploitation and continuous aquifer depletion. The restrictions apply to all classes of ground water user. In São Paulo City itself, use constraints are in place for zones of (proven hazardous) industrial ground water contamination. However, attempts are made to keep most existing waterwells functioning, since complete replacement by mains water-supply is not possible.

Urban ground water – responsibility for governance

Filling the institutional vacuum

Ground water is far more significant in the water-supply of developing cities than is commonly appreciated. Often it is also the 'invisible link' between various facets of urban infrastructure. Most urban ground water problems are very persistent and costly. Thus urban ground water tends to affect everybody, but all too often is the responsibility of 'nobody' (for reasons that will be analysed below). While many problems are 'predictable', few are actually 'predicted' because of this vacuum of responsibility (and therefore of accountability). Frequently 'one person's solution tends to become another person's problem'!

There is a clear need for ground water considerations to be integrated when making decisions on infrastructure planning and investment, whatever its use status. This is not as simple as it might at first appear, because institutional responsibility is at best split between various organisations, none of which take the lead. Regretfully, the reality is that:

- Water-resource agencies rarely have the operational capacity necessary to cope with urban development dynamics.
- Urban water-service utilities in the developing world widely remain 'resource illiterate'.
- Urban land and environment departments have a poor understanding of ground water.

It is important that the corresponding river-basin stakeholder committees (where these exist) are conscious of the need to incorporate ground water resources into watershed planning. They also need to be cognisant of the special problems that arise in this respect where major urban areas are present. However, the members of such committees rarely have enough knowledge of ground water issues or system behaviour to do more than 'flag' the issue for more detailed attention.

The importance of ground water for urban water-supply is not yet reflected by sufficient investment in the management and protection of the resource base. Governments, at all levels from national to local, need to seek realistic policies and effective institutional arrangements to address these issues. They will require the support of the political leadership, improved communication with, and participation of, stakeholders and be informed by sound hydrogeological science.

Moreover, the dynamics of urban development and its intimate relationship with ground water are such as to merit the formation of a 'cross-sector urban ground water consortium' (or standing committee) of all major stakeholders and regulatory departments/agencies. Such a consortium must be empowered and financed to define and implement a 'priority action plan'. Such consortia should be provided with a sound technical diagnostic, by an appropriate group of institute and university specialists. Perhaps the major challenge for such groups will be promoting acceptance of differential municipal land management for important recharge areas in the interests of ground water recharge quality. Also, they will have to confront the impediments resulting from the often geographically fragmented responsibility for land-use and environmental controls.

Confronting the challenge of escalating private use

Private waterwell use in urban areas poses a difficult challenge for water-resource agencies in developing nations. Modern waterwell drilling techniques provide rapid access to ground water for a modest capital investment. This makes it possible for a large numbers of users to exist whose 'hardware' is soon hidden from view. To date, effective management of this situation has often been beyond the capacity of public administrations.

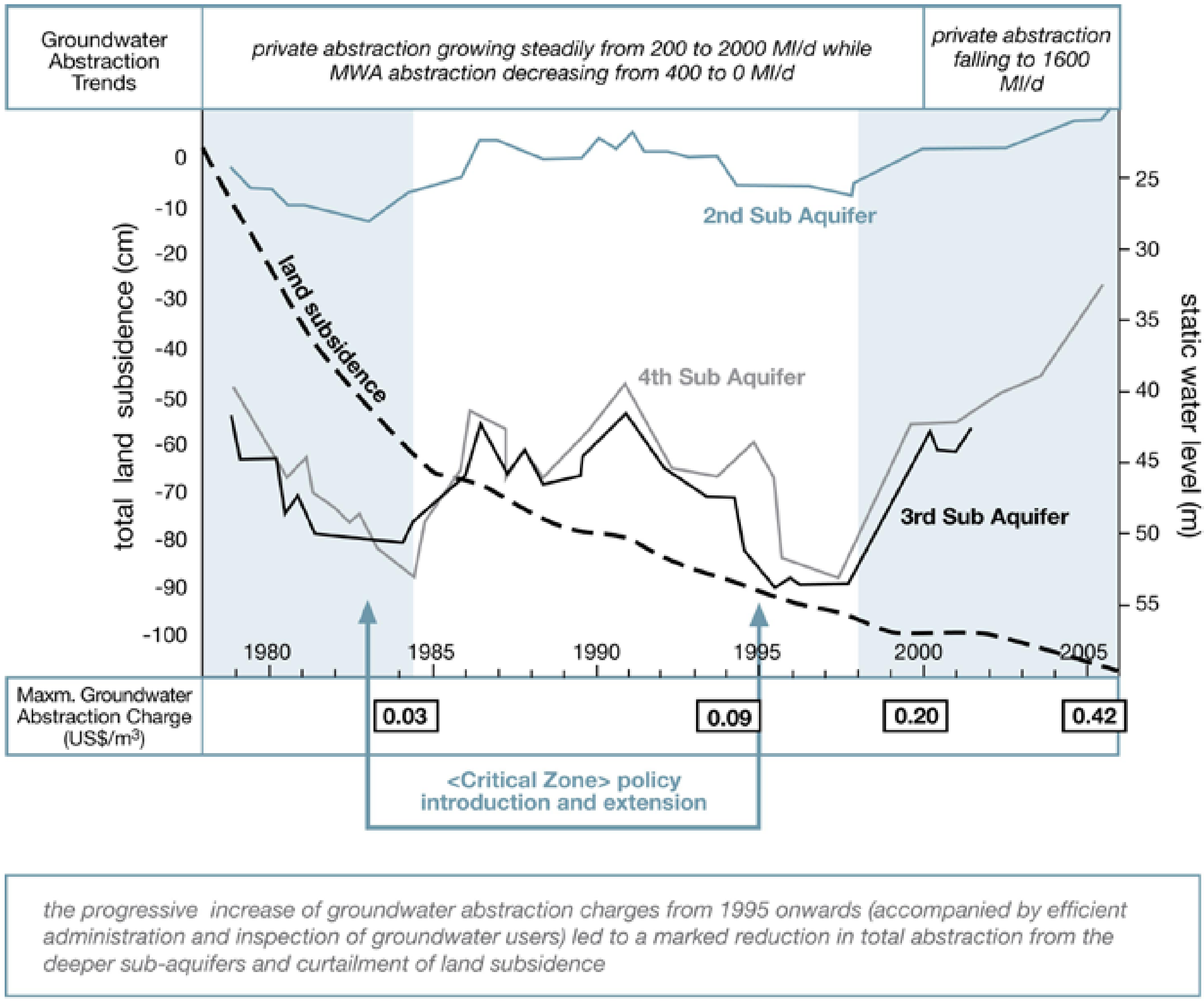

Figure 6. Evolution of ground water abstraction, water levels and land subsidence in Metropolitan Bangkok with improving resource management through waterwell licensing and charging

Most private waterwells are thus, at best, unregulated and at worst illegal. In the longer run this latter is counterproductive for the private user and the public administration and adds to the problem of stimulating a rational policy dialogue and action plan on urban water-supply. If this situation can be regularised, taking advantage of advances in geographical positioning and data-capture systems, it will have clear benefits for both public policy and private users. This will require strengthening the professional capacity and political mandate of water-resource agencies. A judicious use of sanctions may be necessary, but a greater emphasis must be placed on gaining civil-society commitment through effective participatory mechanisms with incentives for 'self-monitoring'.

In the developing world, concerted attempts to regularise private use of urban ground water have been made in a few places. For example in:

- Bangkok, Thailand (Buapeng and Foster, 2008) a combination of a regulatory approach with time-limited licensing of all larger multi-residential, industrial and commercial ground water abstractors is used. Constraints have been placed on private ground water use in critical areas. A progressive abstraction charging plan has successfully stabilised ground water levels and curtailed serious land subsidence (Fig. 6)
- Recife and Fortaleza, Brazil (Foster *et al.*, 2010a) municipal utilities have (understandably) argued for a volumetric water charge to be levied in respect of mains sewer use by private ground water abstractors. This has resulted in a comprehensive inventory of private waterwells on multi-residential, commercial and industrial properties. Charging for sewer use is then by the type/size of property or by metering private waterwell use.

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