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Urban water crisis in Delhi. Stakeholders responses and potential scenarios of evolution

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Abstract

An inadequate piped water supply from the public utility, characterized by intermittence and unreliability, and supplemented by private uncontrolled groundwater abstraction, is a common feature of most Indian cities as well as other developing cities in the world Given the high level of pollution of urban aquifers, the usual diagnosis consists in considering private groundwater abstraction as an undesirable consequence of the mismanagement of the public utility, one which is bound to disappear when proper reforms are implemented in order to extend the reach and enhance the level of service provided by the municipal water supply network. This paper proposes to question this conventional diagnosis with a case study of the capital city of India, Delhi. Based on this case study, the paper shows that the scenario of convergence towards universal access to potable water supply through a centralized public network is not the only long term scenario that can take place in developing cities similar to Delhi. Considering alternative scenarios, in which private coping systems play a role in shaping the long term technical trajectory of the urban water management system, allow the highlighting of certain important policy tools in achieving the sustainability of water management in developing cities.

Introduction

All stakeholders agree on the inadequacy of Delhi's current water supply. Although there are different opinions on the origin of the problem and its solutions, its consequences are clearly seen. The low level of service ensured by the public utility has led the upper and middle classes — as well as industries — to develop coping strategies that represent a complement or substitute to the municipal supply. These might include direct use of groundwater from private tube wells, development of a private small supply network fed with untreated groundwater, or supply by tankers. In most cases, unregulated groundwater abstraction remains the primary source of raw water for those private supply chains (Llorente & Zerah, 2003; Conan, 2004). As a consequence, indiscriminate abstraction has led to a rapid fall in water tables across the city (CGWB, 2005), which threatens the short term sustainability of the system. It is therefore a real crisis that Delhi is experiencing. However, the way the problem is analyzed and the solutions advanced vary among the various type of stakeholder involved in the governance of the system (government, civil society, multilateral organizations, water users), and the different analyses fail to consider all the dimensions of the problem.

The case of Delhi allows the identification of the obstacles to the development of modern water and sanitation services for the city through the traditional state hydraulic model (Bakker, 2005) and shows the growing role of new formal or informal institutional settings as well as technology in framing the overall urban water cycle. The central question raised in this paper is whether these new elements of the urban water system are only temporary solutions to the inadequacy of the centralized water and sanitation system, or if they can be the root of a fundamental change in the technological trajectory of urban water systems in developing cities.

This paper first presents an introduction to the city of Delhi and the institutional setting in terms of governance of urban development and provision of urban services. In the second section, an overview is given of the perceptions of the city's water problem and the different approaches to solving it. In the conclusion, potential scenarios of evolution are proposed. Those scenarios are mainly based on the analysis of the interaction between the two main modes of access to water available to the users: municipal supply network and urban aquifers.

These scenarios will illustrate how the current situation in Delhi may potentially lead to radically different technico-economic trajectories. On one side, private responses to the failures of the public utility can be considered as temporary coping strategies, which would eventually disappear when the service will be improved. On the other side, the current pace of private investment as well as the rapid evolution of technological supply chains for these private solutions might lead to a radical redefinition of the role of the public network in the city's water supply.

An overview of the situation

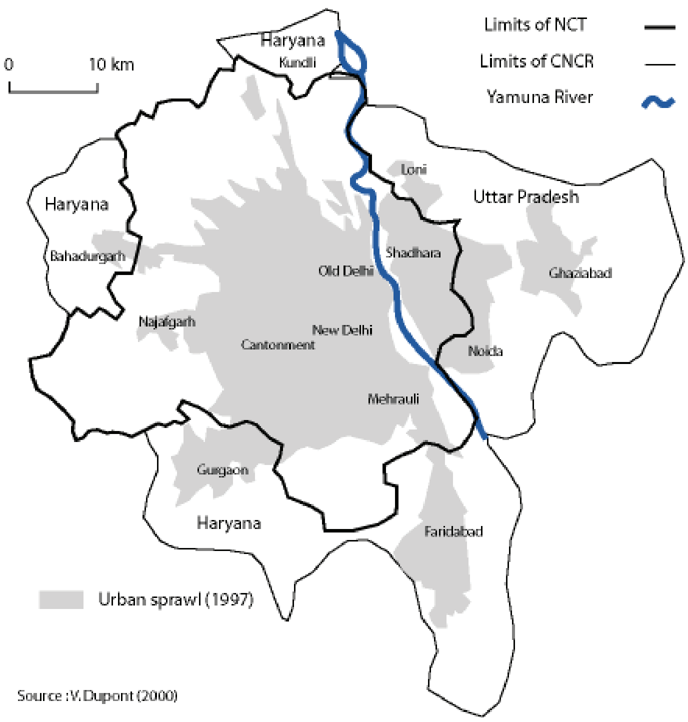
Institutional and geographic characteristics of Delhi

The capital city of Delhi has a specific position in the Indian institutional system. It is indeed located in the National Capital Territory (NCT), which has a status similar to the other states of the Indian federal system.1 Although only 50% of the total area (1483 km2) is urbanized, the urban agglomeration of Delhi extends its limits out of the NCT, with cities like Gurgaon, Noida, Faridabad, and Ghaziabad, growing in the immediate vicinity of Delhi in the neighboring states of Haryana and Uttar Pradesh.

Delhi is currently the fastest growing metropolis in India. Among the six Indian mega-cities with a population over 5 million people, Delhi is the only one whose population grew at an annual growth rate greater than 4% during the last decade as compared to 2.62% in Mumbai, 1.82% in Kolkata and 3.2% in Bangalore.

According to the Census 2001, the population of the national capital territory of Delhi was 13.85 million people, to which can be added the more than 3 million people living in the extensions of the Delhi's urban agglomeration outside the NCT. In 2021, projections of population for the NCT are between 22 and 23 million, and around 10 million inhabitants in the different adjacent cities, making it the second largest urban agglomeration after Tokyo.

Map 1. Urban sprawl and administrative limits of NCT Delhi. (CNCR urban sprawl)



[1] Main differences include the powers of police and land control that are kept under the control of the central government in the case of the NCT.

This position of Delhi both as the center of an urban agglomeration and as an independent state impacts significantly on its access to water resources. Water is a state subject as per the constitution of India. As a consequence, both water supply and water resources management fall under the responsibilities of state governments. In the National Capital Territory (NCT), the public utility in charge of water supply and sanitation — the Delhi Jal Board (DJB) — acts as an independent agency under the authority of the state government. However, given the small size of the NCT, the DJB relies heavily on surface resources which are mobilized outside the NCT. In 2005, the Delhi Jal Board received approximately 1 million m3/day from the Bhakra dam fed by tributaries of the Indus, another million m3/day from the Yamuna, around 0.45 million m3/day from the Upper Ganga Canal, and around 0.38 million m3/day were obtained through exploitation of the local groundwater resources. Its right to those resources depends on several interstate agreements and their application by other states, namely Haryana and Punjab as far as waters from the Indus tributaries are concerned, and Uttar Pradesh and Uttaranchal as far as Ganga river waters are concerned.

Deficiencies in the public water supply

The Delhi Jal Board has around 1.33 million domestic connections, and operates around 11.5 thousand public standposts. Different modes of supply operated by the Delhi Jal Board and estimates of volumes supplied by each mode are presented in table 2.

Table 1. DJB's mode of water supply

Type of supply	Supply mode	Volume supplied in MLD (Million Liters/Day)
Domestic connections	1331820 connections	1124
Commercial and Institutional connections	52623 connections	34
Industrial connections	10876 connections	13
Bulk supply to DCB and NDMC[2]	Bulk supply	158
Public standposts	11533 standposts	221
Water tankers	493 vehicles	10

Sources: Estimations - PWC, GHV, TCE (2004) "Project preparation study – Delhi Water Supply and Sewerage Project" Report prepared for the Delhi Jal Board.

According to data from the census 2001 presented in table 3., the population of Delhi using water from the Delhi Jal Board as its source of drinking water represents around 75% of the population. A significant amount of the population — 18.7% in 2001 — is using water from handpump as its source of drinking water. Given the high risk of pollution of the water obtained from the hand pumps tapping the shallow aquifers, this can be interpreted as a complete lack of access to safe water from the network for this part of the population.

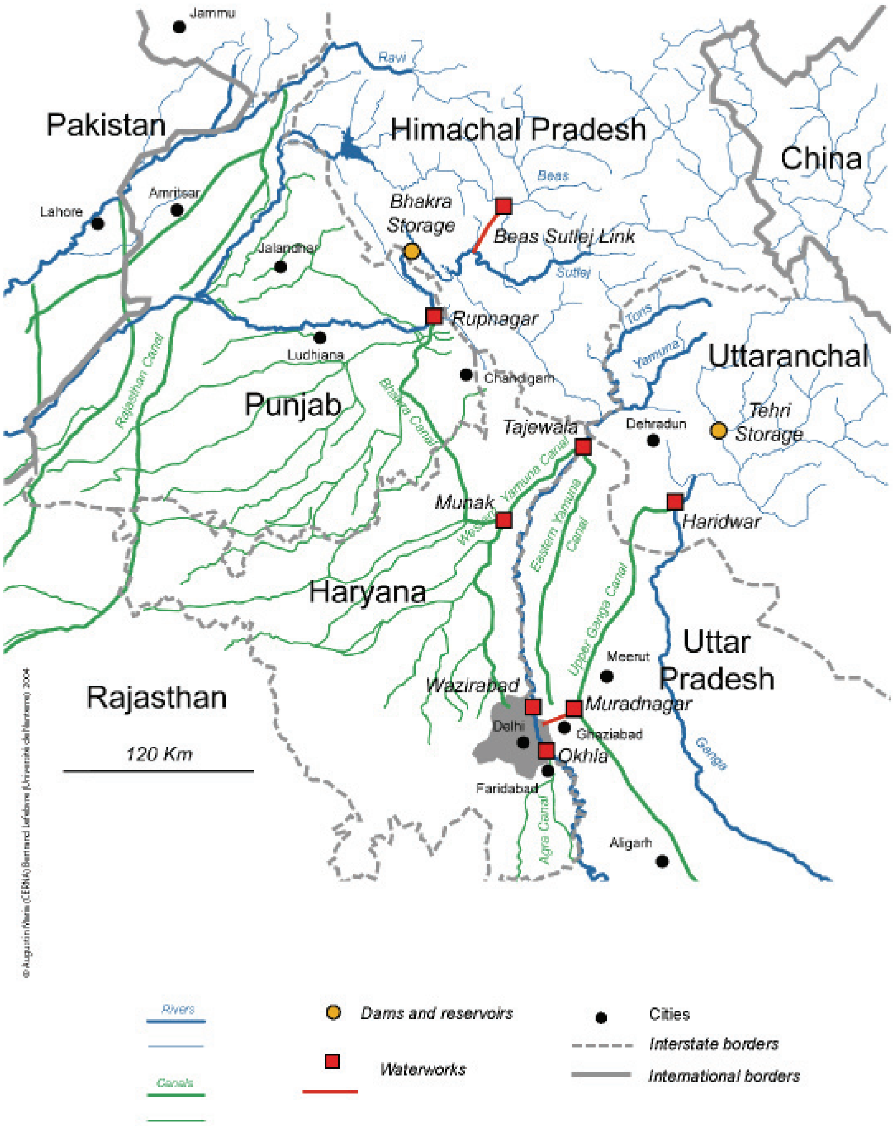
[2] New Delhi Municipal Council

Table 2. Households' source of drinking water (Census 2001)

Source of drinking water	Number of household	Percentage of total
Tap	1,924,149	75.3
Handpump	476,999	18.7
Tubewell	82,519	3.2
Tank Pond Lake	17,409	0.7
Other	53,073	2.1
Total number of household	2,554,149	

Sources: Census of India, 2001

Map 2. Regional environment of Delhi



Even for the population relying on water made available through the network for drinking purposes, the quantity available and the unreliability of supply lead many households to adopt coping strategy that include the use of alternative sources, as well as storage and treatment equipments. Those strategies can be very different among the different categories of users, from the upper-class household living in individual houses using water from its individual tubewell for all uses — treating part of it with a reverse osmosis filter for cooking and drinking purposes — to the household living in an illegal settlement where women will fetch a dozen liters from a far public stand post providing municipal water between 7 a.m. to 9 a.m., using the water from a hand-pump funded by a local politician for the other uses. Zérah (2000) estimated that the total cost borne by households having a connection to DJB's network to cope with unreliability of supply amounted to 3 billion Rs. in 1995 whereas the operational expenses of the Delhi Jal Board on the same year amounted to 1.6 billion Rs.

High discrepancies in access to public mainly determined by tenure status

Inequality in the access to a satisfying water supply from the public network takes the typical geographic shape where peripheral areas get lower volumes per residents, but the main determinant of the inequality is the fragmented administrative status of the housing stock in Delhi. As is the case in many developing cities (UN-Habitat, 2003) the occurrence of slums and other forms of informal housing is a continuing concern in Delhi. This trend is largely attributed to the failure of the public agency in charge of land development, defining and implementing urban policies and housing promotion in the NCT, the Delhi Development Authority (DDA). The DDA's ambitions in controlling urban growth are denounced as being disconnected from reality, and the political debate is particularly fierce between those for asking strict compliance with the plan and others demanding its amendment (Dewan Verma, 2002). According to Bertaud (2005) *"Delhi Development Authority is a good example of Government acting as a monopolist land developers, resulting in expensive and scarce housing, hurting the poorest part of the population in the process."* Although DDA's population growth forecasts to frame the successive masterplans for Delhi proved to be accurate, DDA failed to promote the creation of housing to cater the demand of new populations. As a consequence a large part of the city's growth in the last decades took place in the informal sector, leading to the fragmentation of the housing stock in various categories defined according to legal and technical aspects (table 4).

Table 3. Categories of the housing stock in Delhi

Category	Description
Squatter settlements	Jhuggi-Jhopri Clusters (JJ clusters), or squatter settlements are characterized by the illegal occupation of public or private land. JJ clusters generally belong to the most precarious type of settlement in terms of livelihood.
Legally notified slums:	Although the term of slum is often used as an equivalent of squatter settlements, in Delhi this administrative category refers to settlements that have been brought under the purview of the Slum (Improvement and Clearance) Areas Act of 1956. Those settlements have a legal status unlike the former category, but are considered to be unfit as per sanitary conditions. Since very few JJ clusters have been regularized in the last decades, most of the settlements currently belonging to this category were the one initially falling under the 1956 Act and are located in the old city and its extensions.
Resettlement colonies	Most of public interventions directed towards squatter settlements in Delhi have consisted in eviction and resettlement of the households formerly residing in the illegal settlement in resettlement colonies, usually located in the peripheral areas of the city.
Unauthorized colonies	In unauthorized colony, land is subdivided illegally, usually by illegal developers, and sold as plots. The subdivision is illegal either because it violates zoning and/or subdivision regulations, or because the required permission for land subdivision has not been obtained. Land may be privately owned, under notification for expropriation, urban fringe agricultural land or common land of a village engulfed by city growth. The sale or transfer of land and hence ownership of the plot may have a legal or quasi-legal status, but because of the illegality of the subdivision, plot holders cannot get permission to build. In addition the area is not eligible for an extension of infrastructure services. The inhabitants are not as poor as those residing in squatter settlements and they have some means to make an initial investment on the plot (Banerjee, 2002).
Regularized-Unauthorised colonies	Regularization of unauthorised colonies has been considered by the authorities as early as as 1961 and since then, several waves of regularizations have followed. Regularization provides the residents with an improved legal regime of ownership, and improved infrastructure. However, the unwillingness of plot holders to pay the regularization charges and to follow the regularization plans has led to a partial implementation of the regularization schemes.
Urban villages	There are around 110 villages in the rural-urban fringe of Delhi which have developed upto a level of density which can lead to consider them as urban settlements. A village is declared urban by the Delhi Administration and as such, is to be provided with amenities such as water supply, electricity, sewerage, improvement of roads, parks and community facilities.
Planned colonies	Formal settlements include apartments in DDA flats, apartments in group housing societies, as well as plots allotted to individuals. Although some schemes are supposed to target the lower income groups, formal housing is basically catering to the higher income groups. Some residents of newly developed colonies such as Dwarka and Rohini have complained about delays in the provision of amenities such as water supply.

Figures reported in table 4 show the distribution of Delhi's population in those different categories and the link between housing type, tenure security, poverty and access to basic services. It appears that only 43% of the population lives in settlements where the responsibility of the DJB to provide individual water supply is well defined and implemented. Around 20% of the population, living in JJ clusters (see definitions in table 5) and unauthorized colonies, have no right to individual water connections. In the case of slum designated areas and urban villages, which are settlements with legal status, the features of the urban fabric (narrow streets, ageing buildings) prevent the agency from extending piped services. In resettlement colonies developed to provide housing to populations evicted from JJ clusters, the situation is more ambiguous. Although plots made available for relocation of evicted dwellers are supposed to be provided with access to basic services, access to piped water supply and sewerage is reported to be low in the most recent colonies. (Ali, 1996; Hazards Centre, 2004)

Table 4. **Population distribution by settlement type and obstacles to accessing basing services**

Type of settlement	Population* (million)	Population (% of total)	Tenure	Poverty**	Access to individual connection
JJ clusters (squatters settlements)	2.07	14.84	Illegal	High	No right to individual connection
Resettlement colonies	1.78	12.72	Legal	High	Official right not respected
Unauthorised colonies non regularized	0.74	5.3	Semi Legal	Mixed	No right to individual connection
Regularized unauthorised colonies	1.78	12.72	Legal	Mixed	Good situation
Slum designated areas	2.66	19.08	Legal	Mixed	Restricted by technical features
Rural villages	0.74	5.3	Legal	Low	Not under the responsibility of the DJB
Urban villages	0.89	6.36	Legal	Mixed	Good situation
Planned colonies	3.31	23.69	Legal	Low	Good situation
TOTAL population, millions	13.96	100			

Source:
** Planning Department (2004)*
*** Jain (1990)*

Given the primary role that the status of the different categories of housing plays in the interaction between the residents and the administration to extend adequate service delivery, the understanding of the different urban dynamics controlling the evolution of those figures is critical to the relevance of medium and long term strategies targeting the improvement of water supply and services in the city. Those dynamics include the expansion of the different categories of housing through the development of new formal or informal settlements, as well as the outcome of the different policies oriented towards the regularization of informal settlements such as the demolition of squatter settlement accompanied with the resettlement of a varying share of its population in new resettlement colonies, and the regularization of unauthorized colonies.

Population forecasts used by the Delhi Jal Board to predict the evolution of demand while preparing its reform program are presented in table 6. Data reflects the assumption of homothetic growth of the population living in each category of housing, the assumed growth being roughly one of 50% for each category between 2004 and 2021. This gives an illustration of the lack of coordination between the process of long term planning for water and sanitation infrastructure and the framing of urban policies shaping the scenario of spatial and social development of the city.

Table 5. Population forecasts used for water infrastructure planning

Type of settlement	2004	2005	2006	2011	2021
JJ clusters	2.3	2.374	2.448	2.819	3.413
Slum designated areas	2.957	3.052	3.148	3.625	4.388
Unauthorised colonies	0.821	0.848	0.874	1.007	1.219
Resettlement colonies	1.971	2.035	2.099	2.416	2.925
Rural villages	0.821	0.848	0.874	1.007	1.219
Regularized unauthorised colonies	1.971	2.035	2.099	2.416	2.925
Urban villages	0.986	1.107	1.049	1.208	1.463
Planned colonies	3.672	3.79	3.909	4.501	5.449
TOTAL population, millions	15.5	16	16.5	19	23

Sources: Estimations - PWC, GHV, TCE (2004) "Project preparation study – Delhi Water Supply and Sewerage Project" Report prepared for the Delhi Jal Board.

Two generations of network utility management paradigm

Planning norms, the demand-supply gap, and the state hydraulic model

The way the problem of water supply in Delhi is perceived by the authorities and the general public is highly influenced by planning practices adopted by the Delhi Jal Board, and the Delhi Development Authority. The study of interactions between DJB and DDA for the preparation of the Masterplan of Delhi, which is one of the main tasks of the DDA, shows that most of the planning process relies on a simplistic goal of matching production capacities with projections of assumed demand. Demand projections are simply obtained by multiplying supply norms by population projections[3]. Comparing this estimated "demand" with the installed capacity of 2900 MLD then allows planners to conclude that there is a demand-supply gap of 1180 or 2545 MLD. The logical consequence of this representation of the problem is to draw long term programs of raw water supply augmentation consisting in new dams in the Himalayas, and to plan for the corresponding water treatment capacities. These planning practices leading to supply-led solutions, with an emphasis on hydraulic development as a means of satisfying administratively defined needs are part the characteristics of what Bakker (2005) describes as the "state hydraulic" paradigm, which was the dominant model in most OECD countries from the beginning of the twentieth century to the last decades of the century (Bakker, 2005; Barraqué, 2005). The Tehri dam, built in the state of Uttaranchal, more than 200 km far from the city of Delhi, is the most recent of outcome of the strategy based on large scale hydraulic projects. Delays taken in completion of the project have prevented the Delhi Jal

[3] Whether the norms applied are the one of the Central Public Health and Environmental Engineering Organization which recommends 60 gallon per capita per day (272 lpcd), or DDA's own norms of 80 gpcd (363 lpcd), and given an estimated population of 15 million people, one can come up with an estimated demand of 4080 or 5445 million liters per day (MLD). (put this in the main text?)

Board to start the operation of its last treatment plant, the Sonia Vihar plant, which was the central condition of an improvement in the level of service provided by the utility.[4]Although other similar projects are under consideration, all stakeholders now agree that no significant increase in water availability is to be expected after the Sonia Vihar plant starts its operation.

Mismanagement of distribution, continuous supply, and the "World Bank model" for reforms

Taking into account the fact that no major water supply augmentation is to be expected in the next decade and acknowledging the reasonably high level of bulk water availability in comparison to other Indian and foreign cities, the Delhi Jal Board has prepared a plan for reform of its distribution system, with financial support and technical assistance of the World Bank. As far as water supply is concerned, this plan consists mainly in the experimentation and subsequent generalization of continuous supply, as opposed to the current mode of intermittent supply, which is identified as the main element leading to poor performance of the distribution system.

The government of NCT Delhi, under which responsibility the Delhi Jal Board falls, expresses its vision of the sector reforms' goal as the *"provision of universal continuous (24/7) safe WSS services in an equitable, efficient and sustainable manner by a customer oriented and accountable service provider". (DJB, 2004)* This statement shows a significant departure from the former "state hydraulic model", and a shift from the logic of *intensification* to a logic of *policy reforms* (Pritchet & Woolcock, 2004).

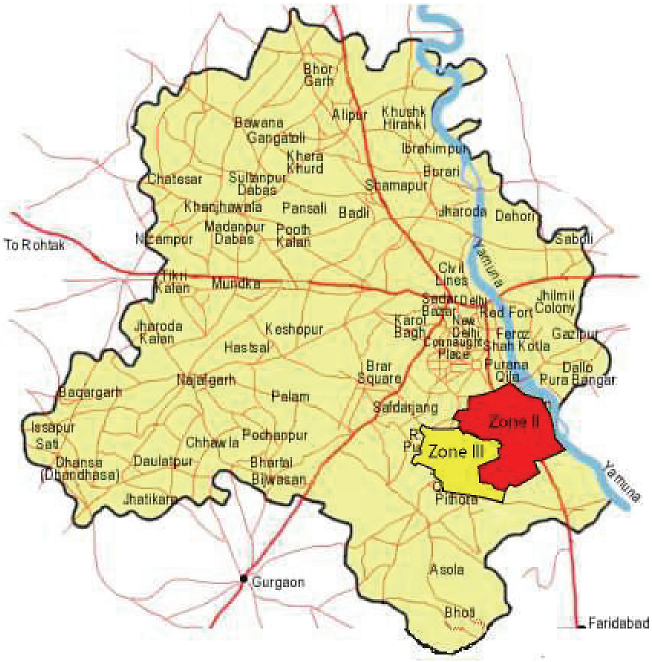
The Delhi Jal Board's reform plan as presented in 2004 was to begin with a first phase including:

- A tariff increase, implemented in December 2004, expected to allow the DJB recover around 80% of its operation and maintenance costs. The tariff increase consists in the modification of the volumetric charge applicable to the four blocks (0-10 m^3/months, 10-20 m^3/months, 20-30 m^3/months, and over 30 m^3/months). The new tariffs represent a significant increase as far as the last blocks are concerned, consumptions over 30 m^3/months being charged 10 Rs./m^3 while the former tariff was 3 Rs./m^3.
- The outsourcing of water supply and sewerage services in two DJB operational zones covering about 12% of the connections (cf. map 3), through management contract(s) for five years, the main objective of this being to gradually move from an intermittent supply system to a continuous supply system. This would be done through technical separation of the two zones from the rest of the system, metering, and complete rehabilitation of the supply system with a target of reduction of technical losses from 40% to 20%.
- Rehabilitation of selected trunk water supply and sewerage infrastructures outside the two pilot zones.

The second phase of the project would consist in the generalization of continuous supply to the rest of the DJB perimeter.

[4] The Tehri dam, under consideration for more than three decades, has been built in spite of many protests regarding issues of population displacement, ecological degradation, and seismic risks. Out of the 10000 MLD capacity of the dam, 733 MLD were supposed to be earmarked for Delhi's water supply, and the Sonia Vihar treatment plant scheduled to treat this water for Delhi was built by a French company and completed in 2003. This plant, with a capacity of 636 MLD was supposed to bring relief to the city from its traditional summer water crises. In 2006 however, the plant is still waiting for the scheduled raw water inflow from the Tehri dam. According to the Uttar Pradesh state authorities, who control Delhi's access to water from the Tehri dam, the dam won't be able to deliver its full capacity before the year 2010.

Map 3. Location of pilot zones selected for experimentation of 24/7 supply



Consequently, in May 2005, the Delhi Jal Board posted two calls for tender concerning two separate six-year management contracts for the continuous supply of potable water in two central areas of Delhi. This strategy has come under a number of criticisms related to involvement of multinational private companies, tariff increases, and lack of provision for the extension of service to the poor (Badhuri & Kejrival, 2005). However, it seems that it is the criticism regarding the involvement of the World Bank in the process of preparation of the reforms and in particular, in the selection of consultants appointed by the Delhi Jal Board to perform preparation studies that lead the DJB to put a hold on the implementation of its agenda and to withdraw its application for the World Bank loan at the end of the year 2005. After being deferred, the reform agenda was submitted for review by an expert committee constituted of Indian utility specialists appointed by the DJB, but the most obvious way out of this political crisis, seems to be the much awaited augmentation of water supply by the new water treatment plant in Sonia Vihar.

The hidden resource: local groundwater and it's non-management

Groundwater and sinking water tables

The way local underground water resources are taken into account in the reflection on the future of Delhi's water supply is rather ambiguous. As stated in the report of the project preparation study of carried out by consultants to help the Delhi Jal Board define its reform program[5], development of local groundwater resources is not considered as a option because of

[5] "In view of the fact that groundwater tables are declining and the quality of the groundwater shows serious negative values (...) , it is no longer feasible to develop new groundwater sources within NCT

its bad state in terms of quantity and quality. Nevertheless, those problems haven't prevented the generalization of private groundwater abstraction. Private groundwater abstraction, made possible by the relative accessibility of the resource, is regulated by the Central Ground Water Authority (CGWA), but the enforcement of this regulation is known to be very limited. Tubewell owners are supposed to register with the Central Ground Water Board. The number of such registered tubewells is currently around 100 000, however, the real number of tubewells might be several times higher. An official from the Central Ground Water Board (CGWB) recently estimated the total number of private tubewells to be around 360 000.(ref?) Precise quantifications of the number of tubewells and the volume extracted from the aquifers are not available, but it is clear that private groundwater use is not taken into account properly in the process of infrastructure planning. The situation is indeed worrying, with groundwater levels going down by more than one metre per year in areas where abstraction is the most intensive. Furthermore,, most of the city is located on aquifers which are subject to saline intrusion. The rapid emergence of a market for individual reverse-osmosis purification systems shows indirectly the central role of private groundwater abstraction in the city water supply (Levasseur & Maria, 2004). Given the current prospects of improvement in the level of service provided by the public supply network, this trend is bound to accentuate in the coming years.

Rainwater harvesting: new paradigm or cosmetic policy?

Although the current informal role of groundwater in the city water supply is occulted in the policies regarding water and sanitation infrastructure, there is a political consensus to promote the development of rainwater harvesting structures. Those structures would typically collect stormwater run-off at the level of a building or of a building complex, and direct the collected water flows to recharge pits for infiltration into the ground. The Central Ground Water Authority provides free consultancy services to individuals willing to install such structures, and rainwater harvesting is even been made mandatory for new buildings and existing buildings exceeding a certain size. Local civil society organizations such as the Centre for Science and Environment (CSE), have been very active in promoting rainwater harvesting. Its potential seems however to be overstated. At the level of an individual building, the quantities harvested appear to be rather small in comparison with water uses. We can take the example of a 100 m^2 residential building with a 100m^2 courtyard, where two families of five persons live. This case provides a rather low estimate in terms of population density. If we consider that only intense rainfall can be harvested, 500 mm can be taken as a proxy of the annual rainfall available for harvesting. Assuming runoff coefficients equal to 80% on the rooftop and 30% for the courtyard, it leads to an annual harvested volume of 55m^3/year. Assuming that 50% of the volumes harvested can be used, the supplementary daily volume available would be of 7.5 lpcd. Similar calculations have been proposed by Soni (2003), who assessed the potential outcome of rooftop rainwater harvesting at the level of NCT and concluded that the outcome would not be higher than 10% of the city's water uses. Therefore, rooftop rainwater harvesting for groundwater recharge, which is the model currently promoted by government agencies by making it mandatory for new buildings and providing advisory services, does not seem to have the potential to be the basis of a new paradigm in terms of urban water management.

The Indian National Trust for Architectural and Cultural Heritage has drafted in 1998 a blueprint for water augmentation in Delhi through the implementation of groundwater recharge at the city level through the rehabilitation of natural water courses and traditional reservoirs located on the NCT (INTACH, 1998). The recommended measures are claimed to have a much higher potential, but very few of them have been taken up by the administration.

territory of Delhi." (4-19)
PWC, GHV, TCE (2004) "Project preparation study – Delhi Water Supply and Sewerage Project" Report prepared for the Delhi Jal Board.

Generally speaking, it can be observed that no public agency nor a private agent will have the proper incentive to implement groundwater recharge as along as the property rights over this common resource remains as vaguely defined as they are currently. (Maria, 2006)

Do it yourself: the current paradigm of water supply in Delhi

The development of alternative systems presents a diverse and rapidly evolving landscape. They are characterized by different institutional and technical configurations and answer to the specific needs of different categories of people. In the current situation, or at least in the situation before the tariff increase mentioned earlier, those systems were not part of an economic strategy. Those systems therefore appear mainly as an answer to the technical deficiencies of the public supply network. Namely, there is a lack of reliability and quantity available at the end-user level that lead individuals to invest in storage capacity, to use groundwater from a tubewell as a complement; or to use the services of private operators of water tankers. There is also a lack of trust in the quality of the water supply which has led to the widespread use of UV filters and bottled water consumption.

Local groundwater is relatively accessible but presents quality problems

For several decades, at the level of one household or a housing society, many residents have been using groundwater as a complement or a substitute to piped municipal supply. The underground resource is relatively accessible on the National Capital Territory with water tables usually between 5 m and 50 m below ground level. Investment in a private tubewell costs between 20.000 Rs. (444 USD) and 40,000 Rs. (888 USD), which is a significant investment for a household. As a reference, the state GDP per head in the National Capital Territory of Delhi amounted to 47 477 Rs. (1055 USD) in 2002-2003. Nevertheless, those investments are often part of the cost of construction of new buildings, since water needed for construction is usually obtained from a new tubewell dug for the occasion. What is more, one tubewell can easily accommodate the consumption of more than 50 households in the case of collective housing. In this case, groundwater clearly appears to represent an economical alternative to municipal water.

Non-residential uses: the exit strategy

If groundwater taking an increasing role in residential water supply, it appears that groundwater has an even higher share in other water uses. A comparison with data available on the share of non-domestic consumption in other Asian cities (PWC, 2004) shows that the share of non-domestic consumption in network-supplied water is particularly low in Delhi. Indeed, this share is believed to be lower than 5% in Delhi, while it is estimated at 15% in Mumbai, and 22% in Calcutta. This share is even higher in other Asian capital city like Jakarta, where the share of non-domestic consumption is reported to be 38% or Singapore and Kuala Lumpur where it is higher than 50%.

Although very little information is available on industrial use of local groundwater, it is agreed that most of industrial water needs in the city are matched through private groundwater abstraction. If the economical factor does not seem to be the main driver of private groundwater abstraction for domestic use, this factor takes another dimension in the case of industries. Industries are indeed subject to water tariffs much higher than the one applicable to residential uses. Even before the 2004 tariff increase, industries had to pay 5 to 10 Rs./m^3 (0.11 to 0.22 USD/m^3) for the water they consumed when the residential tariffs were between 0.35 and 3 Rs./m^3 (0.7 cents to 0.7 USD/m^3). Under these conditions, assuming that groundwater quality does not require treatment by the industry, groundwater use can be profitable even for relatively low consumption around 2m^3/day. With new tariffs going up to 50 Rs./m^3 for consumptions above 100 m^3/month, groundwater use, even if treatment is required, appears as a more reliable and cheaper option compared to consumption of water from the public supply network. This situation has led to the development of a dynamic local private sector offering a wide range of water supply solutions for industries. Those are the same companies that now turn to the residential market.

Groundwater use for domestic purposes in informal settlements: from a tool of "votebank politics" to the development of a local private sector.

Residents of unauthorized colonies, as well as residents of JJ clusters, do not have the rights of formal residents, especially in terms of service delivery, but a vast majority of them have a voting card. In this context, those informal residents are a privileged target for vote bank politics of which shallow wells equipped hand-pumps financed by local politicians are some of the favorite tools. Local politicians generally play an important role in the development of such infrastructures. The three layers of directly elected representatives, that is, Member of Parliament (MPs) sitting in the lower house of the national assembly, Member of Legislative Assembly sitting at the state's Legislative Assembly, and Municipal Councilors, each have a Local Area Development Fund, which they can use to improve local welfare of their electors. Llorente & Zerah (2003) explain how cholera epidemics at the end of the 80's have led the users of shallow wells to diversify their supply strategy by using the services of private tanker operators. Those operators generally own deeper tubewells equipped with electric pumps on land located in the outskirts of the city. In some cases private tankers are reported to carry water illegally obtained from the public network. Although water from those tankers is less subject to bacterial contamination than shallow wells located in the heart of dense residential areas without proper sanitation, the quality of the water they provide remains unreliable. A new form of informal water supply has emerged recently in some unauthorized colonies in Delhi. Raghupathi (2003) reports that small networks developed and managed by local investors have appeared. Those networks are supplied with water electrically pumped from local deep tubewell, and can supply from 50 to 700 households. Water is generally supplied without treatment, for 1 to 2 hours a day. Connections are taken in charge by the customers themselves and cost around 1 400 Rs. Users pay monthly charges of around 200 Rs./month (4.5 USD/month) for a volume supplied of around 0.5 m^3/d.

New planned urban extensions: the case of Dwarka

Levasseur & Maria (2004) have studied the case of the more recent urban extension of Dwarka. The MPD 2001 projected an increase in the population of the National Capital Territory of Delhi (NCT Delhi) from 9.42 Million for the year 1991 to 12.8 Million for the year 2001. The plan proposed urbanization of further 18 000 – 24 000 ha. to accommodate the additional population in urban extension areas like Dwarka, Rohini and Narela sub cities. Dwarka is part of this large urban extensions project and included in the Masterplan for Delhi 2001.

Dwarka scheme, originally known as Papankala scheme, is planned for a population of around 1.1 million People. The total area of the site is 5,648 Hectares, of which 1,688 ha. was already occupied and built up, 1964 ha were developed in Phase I, and 1 996 ha.is still under development in Phase II. The provision of housing in Dwarka takes several forms. Some plots have been allotted to Co-operative Group Housing Societies (CGHS) for the building of multi-storey (6-10 floors) apartment buildings. Around 250 plots of 4 000 to 9 000 m^2 have been allotted to various CGHS. A majority of those apartment buildings are still under construction. DDA has also taken up the construction of flats of various categories. Those flats are generally located in so-called “DDA pockets” and come under the forms of 4 floors buildings. Some individual plots are also offered for further development. Some resettlement colonies have also been developed in the sub-city. When the study was carried out, the population of Dwarka was estimated around 125 000 people but this population is now subject to rapid growth thanks to the Delhi metro connection to the city center.

The lack of coordination between the land developing agency (DDA) and the agency in charge of water supply and sanitation (DJB) has created a set up in which willingness to pay and capacity to invest shows a mismatch with the level of service provided by the public agencies. Dwarka was supposed to be supplied with additional raw water made available by the completion of a conduit in Haryana reducing leaks in the transport system making water from the Indus system available to Delhi. Considerable delays in the completion of these works have made water supply to Dwarka very problematic. In this condition, cooperative group-housing societies, gathering 60 to 180 households, have developed a great variety of coping systems based on conjunctive use of network and ground water, and various strategies of treatment, storage, mixing and distribution of various water flows. In DDA pockets, all the initiatives have been taken at the individual level and therefore appear quite limited in capital investment and complexity in comparison with the ones taking place cooperative societies. This can be explained by difference in income between residents of DDA pockets and residents of housing societies, the former typically belonging to the lower economic layers of the population. But the main factor having an impact on the development of alternative systems at the collective system appears to be the institutional capital that the existence of the cooperative society provides.

The institutional conditions for the emergence of collective action — at the scale of cooperative housing societies — created by the gap between the investment capacity of the residents and the level of service offered by the public utility therefore appears as a fertile ground for the rapid emergence of a new technology supply chain. This supply chain is however at an early stage of its development. Indeed, surveys carried out in cooperative societies also showed a great diversity of technical set-ups. The systems were sometimes conceived as retrofitting, after the residential complex was built. In most cases, however, the system was defined as one of the responsibility of the architect hired to design the residential complex. Consultants hired are provided with terms of reference defining the water sources available, that is water available from the network and characteristics of the water available from tubewells, along with needs defined by the residents themselves. Needs are generally defined around 1m^3 per household per day, out of which a certain volume has to be potable, the rest being required to be fit for other domestic uses such as bathing and washing clothes. Significant storage capacities made compulsory by the building bye-laws (around 3m^3 per apartment) can be divided in order to allow for sophisticated strategies of segregated storage and mixing allowing the optimization the quality and quantity of water supplied given the available resources. Those strategies can be refined by the installation of ion-exchange or reverse osmosis at the scale of the residential complex, or at the household level.

As far as costs are concerned, it appears that the conception of these systems is still at the stage of experimentation and costs can still be very high compared to the long term cost of an efficiently run public water supply system as considered by the World Bank for Delhi, that is estimated around 8 Rs./m^3 (0.18 USD/m^3).

Levasseur & Maria (2004) have computed a "total average cost of service" by adding the sum of all operation and maintenance costs and annualized investment costs, and dividing by the total volume consumed. This unit cost allows the comparison of the cost of different systems including the one in which various qualities of water are supplied, to the cost the users would have to bear if they had the choice to consume the same amount of water by using only water supplied by the public network, charged at its long term efficient cost.

It appears that the simplest systems, in which groundwater is mixed to network water lead to total average cost of service of 8 to 10 Rs./m^3 (0.18 to 0.22 USD/m^3), which means that there can be an economic competition between the operation of those systems and the exclusive use of water from the public network. The most sophisticated systems which include treatment with reverse osmosis and even gray water recycling lead to costs ranging from 30 to 50 Rs./m^3 (0.7 to 1.1 USD/m^3), which is much higher than the higher residential tariff currently applicable which is 10 Rs./m^3 (0.22 USD/m^3). However, assumptions on the reduction of the cost of the different building blocks of those systems, and the optimization of the overall systems, along with higher estimates of the long term efficient cost of the public supply network could lead to look at a scenario of economic competition between the two systems as a plausible alternative.

The development of a new market for "water solutions" designed for residential complexes and the question of sustainability

The example of the cooperative group-housing societies in Dwarka sheds light on a rapidly growing market for integrated technologies that is attracting an increasing number of local companies that started their business with industrial customers. New residential complexes located in the periphery, similar to the one studied in Dwarka, will represent the bulk of the future increase in Delhi's formal housing. Water provision by the Delhi Jal Board to these peripheral areas still appears as highly unreliable. This constitutes a privileged ground for the emergence of a demand for solutions allowing new residents to adapt the design of their building to existing water sources, be it the public network or groundwater. Currently, those systems lead to an unsustainable use of groundwater. But the integration of compulsory gray water recycling in the building bye-laws for new residential complexes is being considered, and some companies are already proposing this type of technology to cooperative societies willing to integrate environmental considerations in the design of their built-in water management systems. Therefore, whereas the existing systems appear as costly and environmentally unsustainable, the rapid evolution of the technology supply chain, and the growth of the market size, along with the perspective of additional incentives provided by public policies, allow assuming rapid cost reductions that could lead decentralized systems to be competitive with the centralized public system.

Scenarios of evolution and their determinants

What will be the role of alternative systems in the long term dynamic of water supply system development?

As illustrated by the examples presented above, collective action at the city level lacks clearly defined goals in accordance with available means. On the other hand, private initiative, be it from individuals, residents groups, industrial, or NGOs, seems to be a powerful factor for evolution. Two basic scenarios illustrate alternative conceptions about how the interaction between private and public initiative can shape the long term dynamic of evolution of water supply in Delhi

In the first scenario, the main assumption is that, sooner or later, Delhi will converge towards the same technical and institutional set-up as the ones in cities from the industrialized countries, that is, universal coverage with in-house continuous supply of potable water for uses, through a centralized system regulated by the public authority. All the current divergence from this conventional set-up are therefore considered either as temporary adaptations to low income levels of the poorest segments of the urban population, or the consequences of mismanagement of the public utility. This first scenario is the one that underlines most policy recommendations, either falling in the "state hydraulic" paradigm or its more recent neoliberal alternative. The main trends in this scenario can be summarized: a combination of management reforms and technical improvements to the centralized system improve the service to people connected to the network and turns them into creditworthy customers, while lower cost collective options are provided to unconnected populations until the increase in their income allow them to connect themselves as individual customers.

In the second scenario systems emerging from the coping strategies of the different types of users can constitute the germ of an alternative trajectory of the urban water system, a scenario which questions the main assumption of the convergence central to the first scenario.,.

Two distinct dynamics are to be considered to assess the probability of the two scenarios. The first one being the evolution of the understanding of the situation by the public authorities and consequent policies and regulations, and the second being the individual behaviour of water users trying to optimize their access to water given the existing possibilities in terms of public service, the definition and enforcement of regulations, and the state of the local natural environment.

Therefore, two kinds of questions emerge from the study of the probability of the two scenarios. The first one is about the ability of public authorities to impose the first kind of scenario, and the second deals with the desirability of this option.

The overview of the current situation in Delhi leads to think that the answer to the first question could change rapidly in the coming years. Considering the current costs incurred by residents investing in complementary systems to improve their water supply, a reform of the public distribution system leading to a continuous supply of potable water at a tariff covering operation and maintenance costs would lead most residents to abandon the use of their complementary systems. Even if the tariffs had to be increased in the future - in order to recover costs of capital replacement, network expenditure, and more stringent environmental policy - one can assume that an effect of technological lock-in similar to the one observed in the industrialized countries would lead most users to accept some increase, at least in the medium term. However, this answer to the question on the ability of the public authorities to lock the higher income sections in the first type of scenario can change in a very short period, since we have seen that some alternative systems implemented at the scale of collective housing complexes can already enter in economic competition with water supplied through the public network. The rapid evolution of technology supply chains and the associated decrease in costs can therefore prevent public authorities from directing the system into the trajectory of the first scenario, unless regulations such as compulsory connection to the network and banning the use of groundwater can be enforced successfully. Even if we imagine that policies can force the system to evolve in the direction of the first scenario, the question of the desirability of this scenario would still be open. Indeed, the current evolution of the alternative systems described above goes in the same direction than theoretical contestations of the centralized paradigm (Pinkham, 1999).

However, there are several key questions that still have to be answered to make an informed decision about which scenario should be privileged in framing strategic policies for the long term improvement of water and sanitation services.

Conclusion: questions to be answered in order to assess the alternative scenarios

What will be the city like?

Demographic models are available to estimate future population growth in Delhi. But how does it translate into framing practical strategies to ensure efficient provision of basic services? In order to understand how urban dynamics have to be taken into account for the framing of a long term strategy for optimal development of water and sanitation services, one has to:

- Anticipate the socio-economic profile of the population: how many residents, and type of income distribution.

Urbanization is mechanically associated with the development and economic transition of any country. In India, 600 million people are still dependent on agriculture and the economic transition from a rural agrarian society to an urban industrial society is still a long term phenomenon. One can assume that in the next decades, a sizeable part of the city's inhabitants will be living as informal residents, with low incomes linked to incomes available in the rural sector. In this sense, it seems reasonable to recognize that Delhi is and will remain for a next decades a "poor city".

- Imagine how feasible urban policies can have an impact on the social and spatial organization of the city: who lives where, and with what legal status?

Access to the city means access to the labor market and access to the housing market. The study of residential choices of the poorest city dwellers reveals that informal housing constitutes one of the elements of a negotiation between workplace proximity, cost of housing, and livelihood. It is the role of urban planning and housing development policies to shape the city in a way that these can be resolved.

- Analyze how the former elements impact the relation between urban dwellers and the agencies in charge of service provision

Spatial and legal characteristics of housing act as a constraint to service provision. Various initiatives have shown that different kinds of partnerships involving civil society organisations can address these constraints. However, on the long term, the same question that was applied to technical systems can be applied to these institutional set-ups. Are they to be considered as a temporary compensation for the lack of coordinated service delivery agencies and one part of the population continuously considered as informal? Or are they a necessary constituent of the social structure of a poor city?

How will the relation between the city and its environment?

The European Framework Directive (EEC 2000/60) issued in October 2000, defines "the good ecological state" of waters in the community by the year 2015 as its main target. According to Barraqué (2005) experts wonder if the European Commission and Council are not fixing an impossible target of 'cleaning all water in 15 years'. The social acceptability of the full cost recovery of the investments needed to achieve those targets is indeed questionable. The "strong sustainability" acceptance of sustainable development implies that any environmental degradation has to be avoided. But it seems hard to imagine how any country, especially India, could avoid any environmental degradation in the near future. One has to determine if current environmental degradations are only the result of mismanagement or if, according to the "Environmental Kuznets Curve", they correspond to a logical stage in the process of economic development. It is surely somewhere in between. The fact is that if India had to comply today with the European Directive, it would have a major impact on the redefinition of the optimal technical system to be put in place. But is such a target relevant? The gap that already exists between financial capacities of Indian cities and the investment needed to comply with the norms defined by the pollution control authorities does not allow considering those norms as a practical tool for environmental management. The relevance of current investment strategies resulting from the existing institutional set-up can be questioned. A long term perspective on realistic goals and how they can be achieved at the lowest cost and with the most sustainable result could lead to reconsider the tools used for regulation, with a priority given to incentives towards source control and reuse.

Can Delhi afford to loose its groundwater resources?

In spite of the critical role of local groundwater resources in the city's water supply, it remains practically unmanaged. Groundwater is considered as a buffer resource, which use is inevitable in the current situation, even if its formal development and management is not considered as a relevant option on the long term. But the paper shows that local aquifers are not only a critical element of the urban water system on the short term, but that their storage and treatment capacity can also play a central role in the long term scenario of development of a sustainable urban water system. The central problem of urban groundwater management is similar to the ones observed in other areas of urban management such as housing policies. It is the inability of public agencies to deal with existing situations that they regard as sub-standard with other attitudes than the one of implicit occultation. As an urban development agency has to learn how to manage substandard housing with tools other than massive eviction and relocation programs, agencies in charge of urban water management have to develop strategies to manage resources subject to degradations that make them sub-standard.

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