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Groundwater Use in Metropolitan Fortaleza - Brazil
Evaluation of Strategic Importance and Potential Hazards

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This case profile interprets and extends the results of a World Bank-financed survey of water wells in the Fortaleza Metropolitan Region, which was executed for SRH-Ceará (by a Golder Associates-Pivot Consortium) with inputs from COGERH and CAGECE during 2002-05. The survey recorded an unexpectedly large number of water wells and provides insights into the very important (but at present completely informal) role played by groundwater resources in the overall water supply of one of Latin America's fastest-growing cities. An urgent need to establish an institutional mechanism of integrating the groundwater dimension into urban infrastructure planning and management arises. Similar situations exist in various other cities in Brazil (including São Paulo) and more widely.

Background to Urban Water-Supply Provision

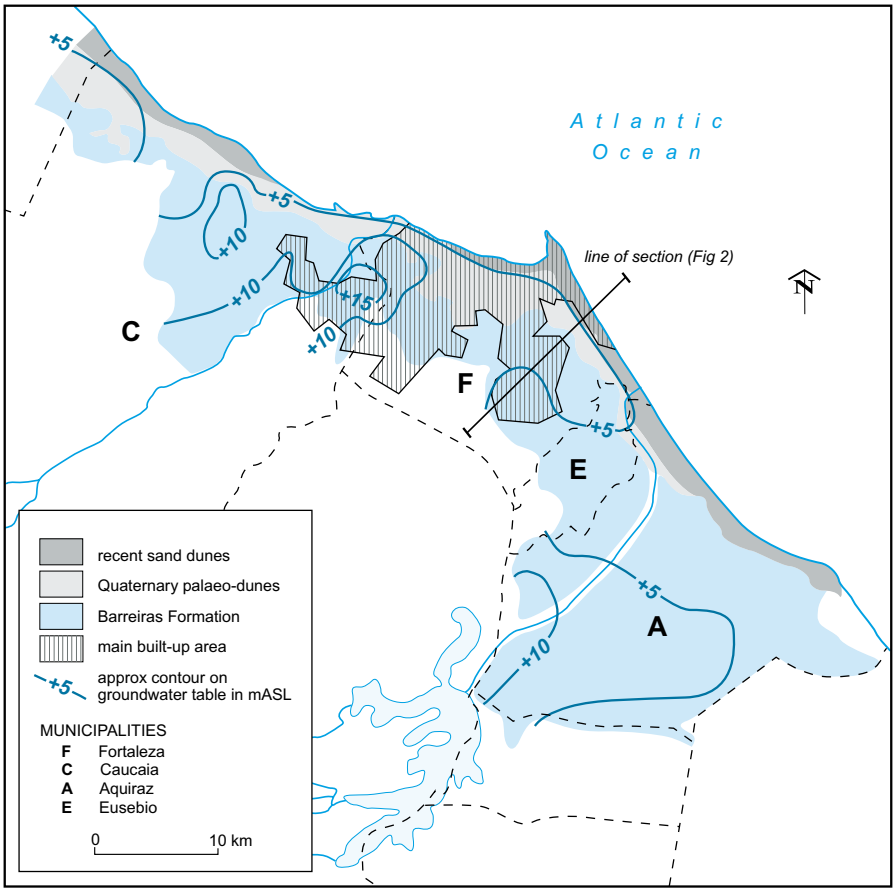
- Over the last 50 years Brazil has seen exceptional rates of urban population growth and development – in 1950 there were around 19 million urban dwellers (37% of the total) whilst by 2000 the figure had grown to 137 million (81% of the total).

- Metropolitan Fortaleza (the main focus of this paper) includes 13 municipalities with a total area of 4,966 km^2 and current population of 2.98 million, which is growing at 3.5%/yr. Amongst these, Fortaleza Municipality itself (2.14 million) is a virtually-continuous urbanized area (Figure 1) (except for an 'urban ecological park'), which has population densities in the range of 2,000-7,000/km^2 and a very high degree (perhaps over 60%) of surface impermeabilization.

- The remainder of the municipalities have much lower population densities (40-400/ km^2), and usually a significant proportion (more than 10%) of 'rural dwellers'. Although the overall area of agricultural land is small (about 4%), there is some important cashew nut, bean, maize, coconut, banana and sugarcane cultivation and livestock rearing.

- Mains water supply is provided by CAGECE, at present largely from a series of impounding reservoirs, canals and treatment plants on neighboring small rivers, who provide service to some 60-70% of the population. The system has a 'guaranteed yield' of 570,000 m^3/d (6.6 m^3/s), which is not sufficient to meet current peak demand (put in excess of 10.0 m^3/s).

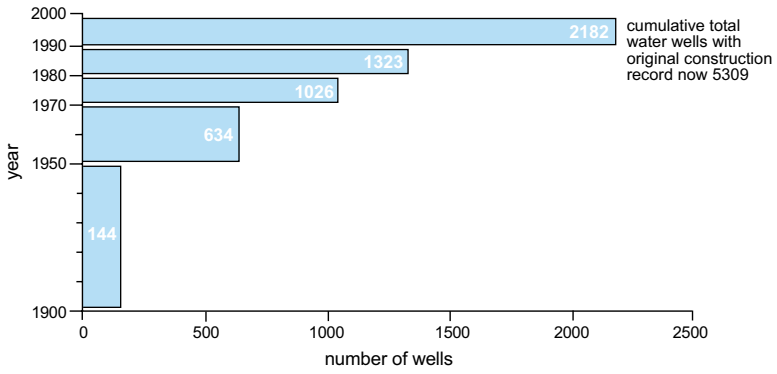
Figure 1: Hydrogeological sketch map of the Fortaleza Metropolitan Region



- The unreliability of service provision in certain zones, and earlier periods of near collapse of the mains water-supply system during extended drought (most recently in 1998), have led to some 40-60% of the population also having constructed water wells for direct self-supply from groundwater (Figure 2) – this being especially true for multi-residential properties but also to considerable degree for uni-residential dwellings. Industry is also an important groundwater user, with the major industries being textile manufacturing, leather tanning, clothing production and the processing of a wide variety of foodstuffs. The economically-important recreation and tourist industry is also highly-dependent on groundwater availability – with major use for laundry installations, garden watering and sports facilities.

- The cover of mains sewerage has expanded rapidly in recent years – in the case of Fortaleza Municipality itself with coverage increasing from less than 10% of the population in 1990 to approaching 50% in 2004. However, even here there remains substantial discharge of wastewater via septic tanks and cesspits to the ground, and elsewhere only small areas have sewer coverage.

Figure 2: Evolution of waterwell construction in Fortaleza Municipality

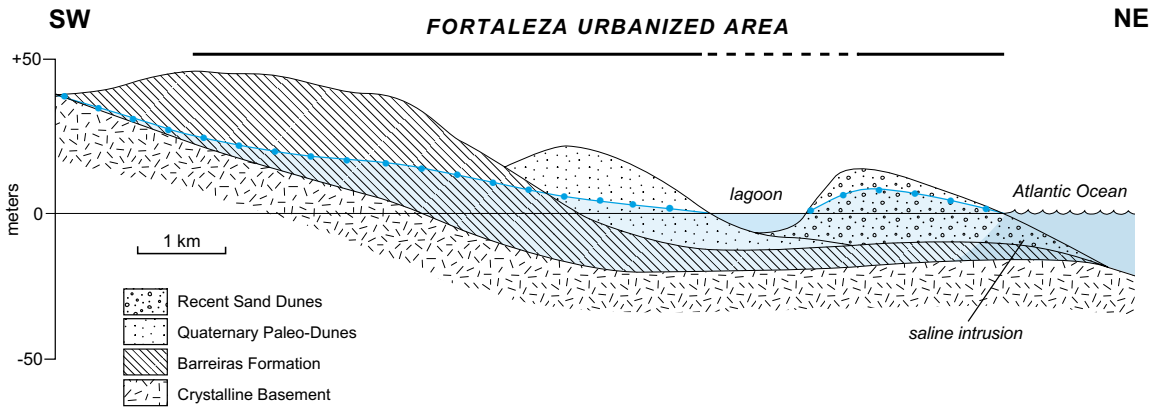


Geohydrological Setting of the Conurbation

- The Tertiary-Quaternary cover formations comprise a complex laterally-variable coastal strip aquifer system (Figure 1) (mainly of aeolian and fluvial deposition), with a thickness ranging up to 60 m or more at maximum and a topographical expression of low hills of 25-50 m height (Figure 3). The aquifer system quite widely has a total saturated thickness of 30 m or more. The Tertiary Grupo Barreiras, which overlies the Pre-Cambrian crystalline basement rocks, comprises around 50m of sands with interbedded lenses of clay or silt, and is overlain by up to 30 m of Quaternary dune sands (both palaeo and recent) with occasional interbedded fluvial sands, silts and clays.

- Metropolitan Fortaleza has a humid tropical climate, although it is markedly drought-prone. The rainfall data show a fairly wide variation according to aspect, distance from coast and altitude of the location – with averages mainly in the range 800-1,200 mm/a (with over 90% falling in the months of February-May). In dry years the rainfall can reduce to less than 25% of the average and these occur with a frequency of 1 in 5-10 years.

Figure 3: Typical cross-section illustrating hydrogeological conditions on the Fortaleza coastal belt

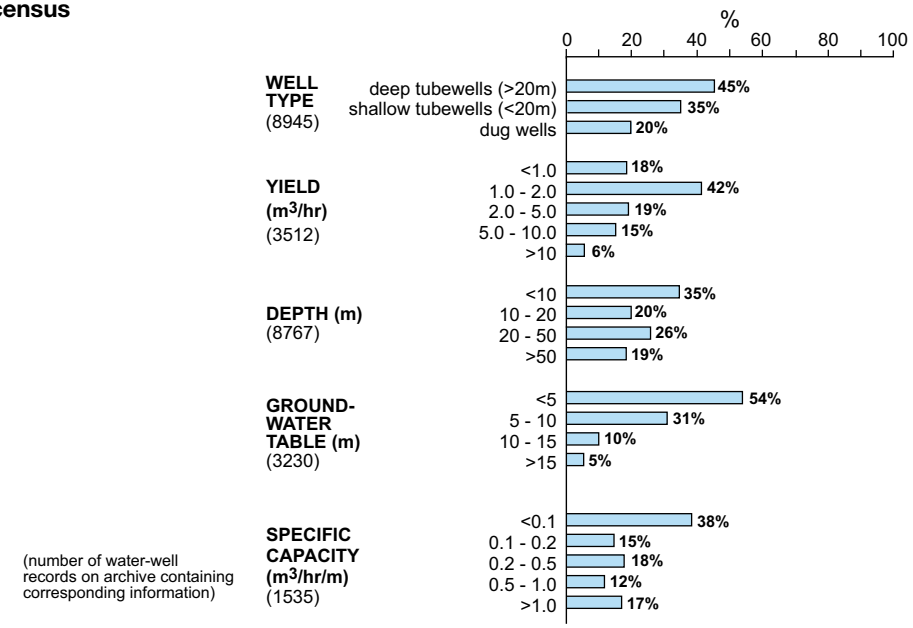


- The replenishment of the coastal strip aquifer takes place by a variety of mechanisms, none of which has yet been systematically evaluated and indeed could prove difficult to quantify with precision :
  - diffuse recharge of wet season rainfall excess to plant requirements – although this will have been progressively reduced in highly-urbanized areas due to land surface impermeabilization
  - infiltration of surface water along riverbeds and in lagoons collecting runoff from the largely-impermeable basement rocks of the interior
  - leakage of water mains in highly-urbanized areas – a component that will vary significantly in time, with the extension of mains water coverage and campaigns to reduce leakage losses (at present CAGECE have 32% of 'unaccounted for water' of which at least 15% is subsoil seepage with higher proportions in the older urban areas)
  - ground discharge of wastewater from septic tanks and cesspits, mainly in areas without a main sewerage system – another component that will vary significantly with time given the process of initial urbanization and then subsequent extension of mains sewer coverage
  - infiltration of excess surface water application in irrigated agriculture – a small and decreasing component.
- A detailed picture of groundwater piezometric contours and flow regime is not yet available, but an indication is given in Figure 1. In most cases the water table is said to be in the range 2-15 m below land surface and the aquifer system is locally susceptible to sea-water intrusion and everywhere relatively vulnerable to pollution.

Outcome of 2002-03 Water well Inventory

- The survey of 2002-03 placed some 9,920 water wells on inventory (although it is suspected that the true total is nearer 12,000) – this compared to about 1,700 in 1980. Of those wells surveyed 8,945 were fully equipped (Figure 4) – with 45% being tube wells of 20-80 m depth, 35% tube wells of less than 20 m depth (both of which were mainly pvc-lined) and 20% concrete-lined dug wells (cacimbas). Of these equipped water wells, 85% are used for domestic water supply (at all scales from individual households to condominiums and municipal bore holes), 7% for industry, 5% for agriculture (mainly

Figure 4: Classification of equipped water wells in Fortaleza Metropolitan Region from 2002-03 census



tropical fruit and vegetable production) and 3% for recreational establishments.

- On the basis of the extensive information in the inventory, which included statistics on smaller subsets of water wells for drilled depth, groundwater level, potential yield and specific capacity (Figure 4) and various other assumptions, a number of important estimates have been made on a preliminary basis :
  - the value of sunk capital in private groundwater supply across Metropolitan Fortaleza is a minimum of (Brazilian Reias) Rs 51 million (approx US$ 23 million) (Table 1) and this figure can probably be increased to above Rs 70 million (approx US$ 32 million), if an allowance is made for non-operative and non-inventorized wells

Table 1: Estimate of private capital investment in groundwater supply production in Metropolitan Fortaleza

TYPE OF WELL	No. OF WELLS SURVEYED	TYPICAL UNIT COST (Rs)	INVESTED CAPITAL (Rs M)
Deep Tube Wells (50m /pvc-lined)	3,130	10,000	31.3
Shallow Tube Wells (15m/pvc-lined)	4,020	4,000	16.1
Dugwells (10m/concrete ring-lined)	1,790	2,000	3.6
TOTAL	**8,945**	-	**51.0**

  - the total potential groundwater production capacity in Fortaleza Municipality (which may only be fully realized in drought years when demand is greatest and CAGECE supply availability is least) is put at 146,300 m^3/d (Table 2), and the corresponding figure for Metropolitan Fortaleza is 200,700 m^3/d
  - these groundwater use figures represent 29% and 36% respectively of total water-supply provision under drought conditions (the difference reflecting greater dependence on groundwater in some of the 'outer municipalities'), and higher proportions (approaching 40%) on the basis of delivery to the consumer given the relatively high level of system losses due to leakage and other factors (Table 2).

Groundwater Quality Investigation & Monitoring

- The 2002-03 survey and its follow-up generated for the first time a significant amount of groundwater quality data through two separate programs :
  - reconnaissance sampling of water wells in selected micro-areas of various municipalities with a small suite of laboratory analysis (total 200 samples to the SEMACE lab)
  - 6 monitoring campaigns during the period November 2004 – March 2005 (Table 3) focussed on the strategic micro-areas, using field equipment for pH, DO, TDS, Cl, NO_3 and NH_4 to test 75-175 samples in each campaign.
- Amongst the 200 representative wells selected for the reconnaissance groundwater quality investigation 72% were found to have some quality concerns :
  - elevated NO_3 or NH_4 concentrations (mainly in more densely-populated zones of Fortaleza Municipality) apparently derived from a component of wastewater infiltration (22% of the samples collected exceeded the Brazilian drinking-water guideline for NH_4-N of 1.5 mg/l)
  - in some areas elevated EC (over 2000 uS/cm) probably related to salt-water intrusion.

Table 2: Estimates of total potential groundwater supply compared to surface water usage in Fortaleza Municipality

TYPE OF USE	No. OF EQUIPPED WELLS	PUMP CAPACITY/ OPERATION*		ESTIMATED ABSTRACTION (m^3/d)
		m^3/hr	hr/d	
Domestic	5320	2	5	53,200**
Industrial	570	10	16	91,200
Agricultural	0	4	12	0
Recreational	190	2	5	1,900
Total Direct Supply (from groundwater)	6080	-	-	146,300
CAGECE Public-Supply from Surface Water***				501,100
Proportion from Groundwater	*of gross total*			29%
	*after discounting mains leakage****			39%

* *no metering of groundwater extraction or pump operating time , thus estimates based on local knowledge of typical situations*
** *includes only volumetrically-significant CAGECE groundwater abstraction of 2,300m3/d from 6 waterwells in Caucaia*
*** *based on secure yield estimates of 5.8 m3/s for Fortaleza Municipality and 6.5m3/s for Metropolitan area respectively*
**** *based on water-supply available to consumer after deducting system losses estimated at 25%*

- The results of the subsequent field sampling campaigns have some inconsistencies, and do not yet generate a reliable description of the situation in the micro-areas or an adequate interpretation of spatial and temporal variations across the aquifer system. In particular :
  - the NH_4-N analyses are of special concern since the interpolated maps give the impression of very widespread high values, and the presence of significant NH_4-N is normally taken as indicative of active wastewater pollution and should have been accompanied by microbiological analysis
  - the DO results appear to exhibit a cyclic trend correlated with major rainfall variations, but this is not fully substantiated – although there is correlation between DO, NH_4, NO_3 and Cl.

Table 3: Summary of field groundwater chemistry sampling campaigns in the Fortaleza Metropolitan Region during December 2003 – March 2005

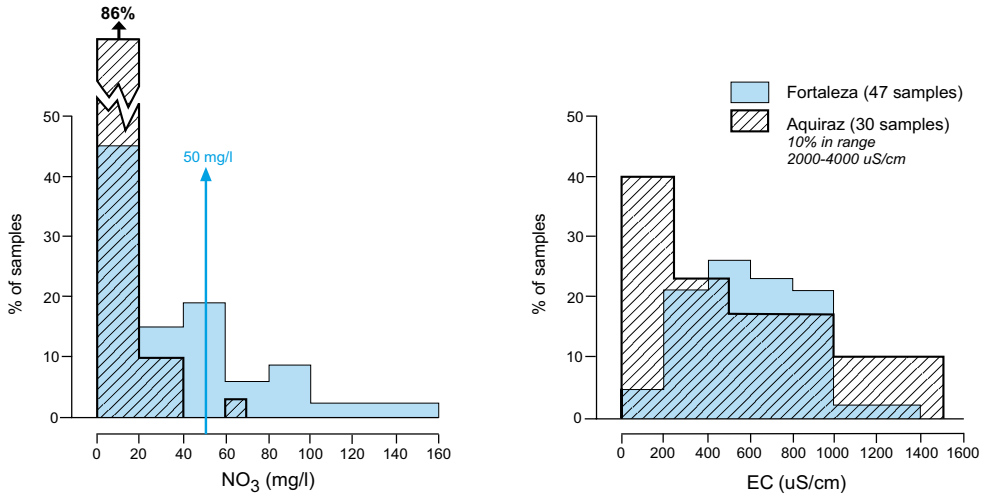
DETERMINAND	SAMPLING CAMPAIGN*				CORRELATION DIAGRAMS
	1 (22 Dec 2003) D	2 (1 Mar 2004) W	3 (13 Dec 2004) D	4 (5 Mar 2005) W	
(No of samples)	117	154	163	174	(No of samples)
T	+	+	+	+	well depth
pH	+	+	+	+	T
DO	+	+	+	+	pH
TDS	+	+	+	+	T, pH
NO_3	+	+	+	+	T, TDS
NH_3	+	+	+	+	DO
Cl		+			T, NO_3

* *campaigns 3 & 4 in May 2004 and Sept 2005 included a much reduced number of samples in only a few municipalities*
W/D indicates wet or dry season conditions

- The general picture which appears to be emerging is that the groundwater quality is generated by the interaction of three main components – excess rainfall during just a few months, continuous water-mains leakage and wastewater discharge from unsewered sanitation – with the latter becoming increasingly dominant in the dry season.

- A substantial monitoring network is slowly being established to evaluate groundwater levels, pumping and quality in more detail (some of which are to be equipped with automatic sensors and telemetry capacity), but significant installation problems have been encountered. It is hoped that results from this monitoring network will resolve some of the outstanding inconsistencies in the groundwater quality status and interpretation.

Figure 5: Groundwater quality survey for water wells in Fortaleza and Aquiraz Municipalities



Integrating Groundwater into Urban Planning

- In one sense the study represents a major step forward in recognizing the importance of groundwater use in the Fortaleza Metropolitan Region, since it took the number of equipped water wells on inventory from 2,400 (CPRM 1997 survey) to 8,945 – and demonstrated that over 1,400 were producing more than 2 m^3/hr with some important multi-residential property, industrial and commercial use. It thus demonstrated a major private (and virtually unrecognized) investment in urban water-supply provision, which will be particularly critical during drought and other emergencies. Furthermore, the larger abstractors are effectively outside the law – since water wells producing more than 2 m^3/hr should be subject to licensing but only 26 permits are held on the COGERH register.
- Current indications are of a high level of domestic usage, especially by multi-residential properties in areas of higher income where pumping groundwater is widely employed to avoid consuming mains water supply at rates above the base highly-subsidized tariff (the first 10 m3 per family/per month is charged at Rs 0.57 /m^3 (approx US$ 0.26 /m^3) increasing to 3-5 times this value for larger use). This could have major financial implications for CAGECE (Table 4), in terms of the 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 water supply – although CAGECE has recently introduced a 'sewer-use charge' based on estimated domestic wastewater generation in properties where water wells are also used for self-supply.

Table 4: Summary of strategic importance and potential hazard of the groundwater resources of Fortaleza Metropolitan Region

ISSUE	BACKGROUND	FOLLOW-UP ACTION
Water Supply Benefits/Costs	incidental combined use of private groundwater and mains surface water can have significant benefits – ensuring continuity of water-provision during drought and to specific consumers difficult to provide from the mains network (such as certain industries and tourist installations) and where poor-quality groundwater is used in garden irrigation and commercial/industrial cooling processes	benefits need to be valued in terms of marginal cost of providing a volumetrically-equivalent alternative water supply and corresponding investment that this justifies in conserving local groundwater and avoiding saline intrusion
Strategic Emergency Water Supply	could be used in event of total failure of CAGECE mains water supply as a result of surface water pollution or extreme drought or other natural disaster	need to identify a group of existing higher yielding water wells to co-opt for public supply
Water Sector Finance	widespread self-supply could have major financial implications for CAGECE, in terms of loss of revenue from potential water sales and difficulties of increasing average tariffs and recovering sewer-use charges from those operating private wells	some form of socio-economic study of groundwater self-supply, and its impact on overall water provision, is needed to inform future policy
Possible Public Health Hazard	poorly-constructed and/or shallow urban water wells can present a major health hazard due to fecal contamination (in event of a serious waterborne disease outbreak) or chemical contamination especially in areas without mains sewerage	potential susceptibility in this regard needs systematic investigation (in terms of aquifer vulnerability and use sensitivity) and appropriate action taken
Future Drainage Problems	should abstraction radically diminish (due to an increased offer of subsidized mains water supply or to quality deterioration and pollution rumours) then groundwater levels would rise progressively to higher than the pre-urbanization condition with serious drainage problems in lower-lying areas	this issue also needs to be systematically appraised

- In consequence of this situation, the overall water supply provision and sanitation/drainage infra-structure of Metropolitan Fortaleza in general, and the Fortaleza Municipality in particular, should be subjected to critical analysis to assess the current influence of groundwater self-supply and associated potential future opportunities and risks (Table 4) – despite the fact that (except in a few limited areas) CAGECE do not view groundwater as a convenient resource for municipal water supply expansion because of the operational complexity of incorporating substantial numbers of individual small-volume sources.

- SRH need to put special emphasis on using the results of the groundwater survey to stimulate high-level discussion and policy-decision on groundwater issues in urban infrastructure planning in Metropolitan Fortaleza, and on a proactive management campaign with clear institutional roles defined for the various actors.

Publication Arrangements

The GW•MATE Case Profile Collection is published by the World Bank, Washington D.C., USA. It is also available in electronic form on the World Bank water resources website (www.worldbank.org/gwmate) and the Global Water Partnership website (www.gwpforum.org).

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