Sustainable Groundwater Management
Lessons from Practice

Case Profile Collection Number 13

The Role of Groundwater in the Water-Supply of Greater Nairobi, Kenya[1]

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The Nairobi City Council–Water Supply Department (NCC-WSD) uses surface water from the Tana Basin as its principal source of water. Groundwater beneath the city is being pumped by private operators (industrial enterprises, commercial users, and domestic wells) in increasing volume to supplement the NCC-WSD supply, but its management has been overlooked. The rapidly increasing number of boreholes have gradually led to falling water-table and increased pumping costs. The current policy of the NCC-WSD is to rely solely on surface water, but it is suggested that for Greater Nairobi as a whole the use of groundwater will become more critical in coming decades to provide adequate service levels for the rapidly-growing urban population and as a strategic reserve in times of drought. An element of groundwater planning and management will be essential if the resource is to play a more optimum and cost-effective role in the overall water-supply system.

STATUS OF NAIROBI WATER-SUPPLY

- Nairobi's demand for water has grown tremendously over the last 10-20 years and the water supply and distribution system has expanded significantly in response. Most of the supply is from the Tana Basin, and is pumped to the city from distances of around 50 km. Following water source expansion projects in 1984 and 1995, the available supply has increased to some 520 Ml/d by 2002, which is adequate to meet the average growth in annual demand up to about 2006.

- Although sufficient under normal conditions, this bulk water-supply is not reliable during periods of drought, and is also endangered by reservoir siltation associated with catchment deforestation. The supply problem is further aggravated by the poor state of the distribution system, which results in about 50% losses due to leakage, illegal connection etc. Another factor affecting supply-levels is the inefficient and wasteful use of water by some consumers, even under the prevailing rationing regime.

- The NCC-WSD used to operate a number of water wells to supply certain sectors of the city that were not connected to the main distribution system, but 10 years ago these were closed and the corresponding areas shifted over to surface water-supply. Nevertheless, groundwater is still an important element of the overall city water-supply through the large number of privately-operated boreholes.

1 The Case Profile is based on the background paper Groundwater in the Nairobi Service Area (no. 9) prepared for the World Bank ESW Report "Towards a Water Secure Kenya; Water Resources Sector Memorandum", April 2004.

- Groundwater abstraction started in the 1930s and has steadily expanded to an estimated 85 Ml/d (85,000 m^3/d) in 2002. which amounted to 25% of the overall water-supply of the population of Greater Nairobi, after deducting that lost in mains distribution that does not reach the consumer.

- Most of the water wells are operated by large private consumers (industrial enterprises, hotel complexes, etc) or by individual residential owners in parts of the city that receive only intermittent supply (eg. Langata, Karen) – wells are often shared with neighbours or water is sold for distribution by tankers at prices of US$53 / m^3 (Ksh 4,000 / m^3). Many private well owners are also connected to the mains water-supply network (which provides cheaper water) but use groundwater as a back-up supply – explaining why installed well capacity (300-350 Ml/d) is much larger than actual abstraction (85 Ml/d).

GROUNDWATER SYSTEM OF NAIROBI AREA

Hydrogeological Conditions

- The Nairobi groundwater basin extends from the zone of north-south rift faulting west of the city (with an elevation of about 2400 m ASL) towards the Athi river floodplain (with an elevation of 1500 m ASL) east of the city center (Figure 1). Volcanic activity has controlled the geomorphologic evolution – the rocks of the Nairobi basin mainly comprising a succession of volcanic lavas and ashes (tuffs), whose thickness reaches some 400 m underneath the city itself and which eastward gradually merge into to the Tertiary deposits of the Athi floodplain.

- The volcanic rocks show a wide range of porosity and permeability and have developed aquifer units separated by lower permeability strata. The aquifers mainly comprise consist the Kerisha Valley Series and Upper Athi Series (transmissivity of 5-50 m^2/d and low storativity). The extension of this multi-layered aquifer system is fairly well known from the many boreholes that have been drilled to depths of 100-350 m (Figure 2).

Figure 1: Location Map

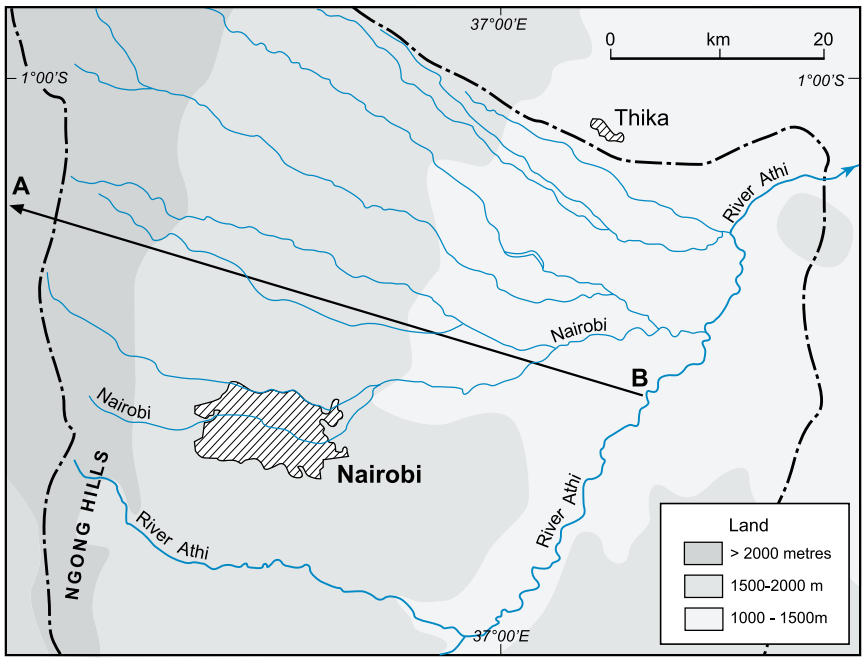
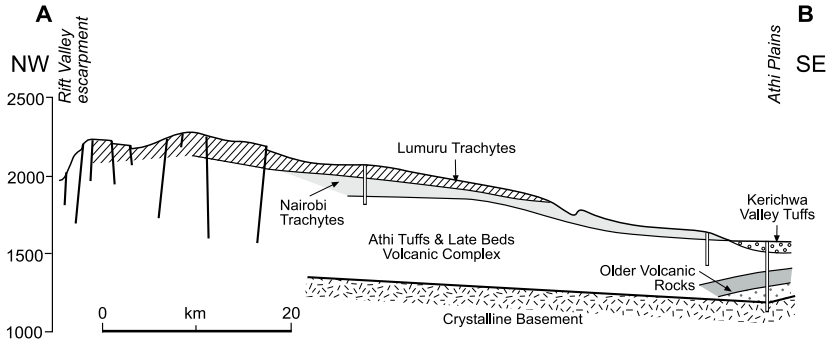


Figure 2: NW-SE Geological cross-section



Groundwater Flow Regime

- Most natural groundwater recharge occurs on the slopes of the rift zone, west of the city, where the volcanic rocks are incised by numerous streams related to fault lines and weathered zones of the previous land surfaces. The upstream portions of these streams form an important source of aquifer recharge. The higher rainfall (1200 mm/a), dense vegetation, permeable soils and drainage pattern along the upper parts of these streams provide good recharge conditions – and although reliable recharge estimates do not exist some 25 Mm^3/a has been estimated to occur on average in this area.

- Recharge also takes place in Greater Nairobi through infiltration of wastewater, water mains leakage and excess rainfall. The total leakage from the water-distribution system is estimated to be 180 Ml/d, but it is difficult to say how much of this reaches groundwater. There is some evidence that part of the infiltration in Greater Nairobi (rainfall averaging 850 mm/a) is intercepted by localized perched aquifers and discharged locally to springs and streams.

- Groundwater flow is principally directed east-south-east from the main recharge area towards the Athi floodplain, where most of the groundwater formerly discharged as springs or seepages into local streams and depressions. Today, the many water wells in Greater Nairobi intercept most of this groundwater flow.

Natural Groundwater Quality

- Fairly consistent data is contained in various reports and shows that the natural groundwater quality is good and reaches the drinking water standards for most constituents, except for fluoride which often exceeds 1 mg/l.

GROUNDWATER ABSTRACTION AND USE

Estimates of Abstraction

- The drilling of boreholes started in the 1930s – and the number of water wells in Greater Nairobi increased from less than 10 in 1940 to almost 2000 in 1997 and further increased to 2250 in 2001 as a result of the drought (Table 1).

Table 1: Recent water well drilling in the Nairobi area

YEAR	1997	1998	1999	2000	2001
number of water wells	32	32	44	61	97
average depth (m)	221	209	218	227	238
average static groundwater level (m)	96	86	97	109	106
average initial pumping yield (m3/hr)	8	9	8	11	12

- Today the wells for commercial, industrial and residential water-supply are metered, with annual reading being the responsibility of the NCC-WSD who are expected to use such measurements as a basis for levying wastewater charges.

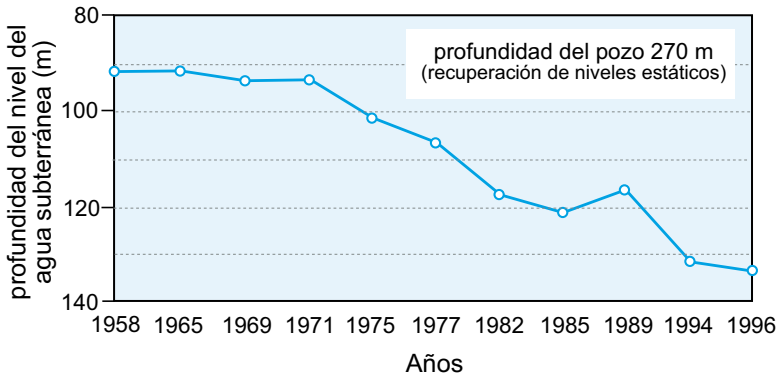
- In 1980 the total abstraction from 1400 boreholes was put at 12 Mm^3/a – this was based on the initial pumping rate during first test reduced by an annual utilization rate ('UAR factor') which takes account of (a) lower unit pumping rates compared to the initial test, (b) different pumping schedules typical of the given use and (c) periods out of production. By 2000 the total abstraction is estimated (on the basis of an inventory of 175 'representative water wells') to have increased to 32 Mm^3/a from 2000 boreholes. In a recent World Bank report, a 'UAR factor' of 0.2 is used to allow for more intensive pumping during a period of increased water shortage, and applying this to the 2250 operating boreholes a total abstraction of 31 Mm^3/a (85 Ml/d) for the 2002 abstraction.

Groundwater Level Evolution

- Groundwater level lowering was first recognized in the Ruarka area in the early 1950's, and the Nairobi Groundwater Conservation Area was created to regulate further borehole construction in 1953. A groundwater observation network was established in the mid-1950s but hardly any groundwater level data are available after 1975. The water-level hydrographs of four boreholes from 1960 show little change until 1970, but those in the Langata area experienced a 4-5 m decline during 1970-75. Biannual water-level measurements in a 275-m deep borehole during 1958-96 by a private company show a decline starting in 1970 and reaching 40 m in 1996 (Figure 3).

- Comparison of data from MWI (Kenya's Ministry of Water and Irrigation) for new water wells of different construction date during the period 1950-98 also indicates a substantial lowering of the groundwater level in the upper aquifer units (above 100 m BGL), but no significant change in the deeper aquifer units, but iso-piezometric maps from 1974 and 1997 suggest little change in groundwater levels on a regional scale.

Figure 3: Groundwater level hydrograph for a water well in Nairobi



GROUNDWATER RESOURCE MANAGEMENT QUESTIONS

Is the Nairobi Basin Aquifer being depleted?

- The long-term groundwater lowering might be taken to suggest that the aquifer system is being depleted. However, the preliminary average recharge estimate (25 Mm^3/a) is in the same order as the annual abstraction in 2002 (31 Mm^3/a). There is, thus, not enough information to attribute the observed water-table lowering to excessive abstraction overall, and it may be a more local effect. Re-evaluation of the recharge-groundwater flow-discharge regime is needed to shine light on the question of what will be the longer term consequences of local groundwater level lowering.

Has groundwater pumping caused land subsidence?

- There is no evidence of land subsidence in Nairobi City due to groundwater level lowering, but this does not exclude the potential risk of local infrastructure and building damage. The presence of clay and silt layers in the shallow sub-soil (Nairobi was once a swampy area in the past), and of unconsolidated fractures and cooling joints, may be potential sources of subsidence.

Has groundwater quality deteriorated?

- The natural quality of groundwater is good, with the exception of fluoride. Lower quality groundwater may be pumped if boreholes are drilled deeper and reach basement rocks. Available chemical analyses show only the major elements, so there is as yet no proof that groundwater does not contain trace elements like selenium or arsenic.

- Another concern is the potential for groundwater pollution that exists is an urbanized environment like Greater Nairobi. There is no hard evidence yet of serious groundwater pollution, but neither has there been much investigation. The upper aquifer is the most vulnerable to potential pollution from the land surface:
  - solid waste landfills and dumpsites
  - seepage from latrines, septic tanks, sewers and drains
  - leakage from underground storage of petroleum and chemicals
  - seepage of industrial effluents
  - infiltration from polluted streams.

What is the maximum sustainable groundwater abstraction rate?

- Current groundwater abstraction amounts to 85 Ml/d, but a more detailed hydrogeological study will be needed to define the long-term sustainable abstraction rate and measures needed to maintain the related recharge rates. Questions that need a clearer answer are:
  - what are the recharge rates from rainfall and from urban water return-flows ?
  - can current groundwater abstraction rates be estimated with more precision ?
  - what would be the impact of increased groundwater abstraction rates ?
  - what are the maximum practical abstraction rates from different aquifer layers?

- Current recharge estimates, potential for recharge enhancement and the large volume of groundwater stored are factors that support the option that larger abstraction may be possible, especially during drought periods. The consistent reports of groundwater level decline, and the fact that deeper aquifer units have already been increasingly tapped suggests that large increases in long-term abstraction are not to be feasible.

GROUNDWATER IN GREATER NAIROBI WATER-SUPPLY

What should be the main role of groundwater?

- At present the main use of groundwater is for domestic water-supply, as an alternative or complementary source to the NCC-WSD mains water. The availability of groundwater as a 'back-up resource' for emergency situations will contribute greatly to the reliability of overall water-supply, and there are a number of reasons why this function should be maintained and better enhanced:
  - most of the surface water-supply comes from two main reservoirs and any the interruption to either of these supplies causes major water-supply problems – for example in 2002 a landslide damaged one of the main external aqueducts causing a 30% supply reduction during 20 days
  - surface reservoirs are vulnerable to drought impacts and their water-supply capacity can be drastically reduced – as was demonstrated during the most recent drought a few years ago.

- The NCC-WSD does not control groundwater use, since all existing water wells are private. However, it is probable that numerous owners will stop pumping groundwater once the mains supply improves and confidence in supply continuity is restored and in many cases abandon their wells – this is because pumping groundwater is the more expensive option for them. If and when this occurs, the NCC-WSD should acquire a network of (abandoned) water wells and maintain them ready for use in case of drought or other emergencies. The present total production capacity of water wells in Greater Nairobi is around 300 Ml/d, which is in the same order as the total water demand and provides a good basis for the design of a ground-water-based back-up water-supply system in the longer run, especially since if only for temporary use there would be no need to undertake treatment to reduce fluoride concentrations.

- In Greater Nairobi groundwater is also used for garden irrigation and livestock watering. A number of boreholes are also used for irrigation in commercial greenhouses, and flower cultivation in particular is a growing activity which could be expected to increase the demand for groundwater.

- It is not known to what extent natural groundwater discharge maintains springs and stream base flows, and thus what will be the environmental impact of increased groundwater abstraction.

How can the strategic role of groundwater be consolidated?

- Groundwater abstraction is currently unmanaged and little monitored. If the expected improvement in the volume and reliability of surface water-supply is achieved, this should create a 'window of opportunity' to order and reallocate the use of groundwater. But to do so, a management plan must first be developed and gain consensus among the major stakeholders (MWI and NCC-WSD) and the different water-user groups.

- MWI and NCC-WSD should first agree and clearly define what should be the communal objectives for future use of groundwater resources, given expected improvements in the water-supply system and taking into account the demands of different water-user groups. The use of groundwater as a strategic back-up during droughts and emergencies should be a potential key objective, and a risk analysis will be required to estimate the amount of groundwater reserve for this purpose.

- Once a revised groundwater use plan has been reached consensus there will be a need to monitor and control its implementation. A numerical groundwater model should be the main management tool to simulate future abstraction scenarios to aid the development of a robust plan. The plan should clearly spell-out the following:
  - minimum information and monitoring requirements
  - institutional requirements and responsibilities for plan implementation
  - regulatory framework for plan enforcement (consistent with the new Water Act)
  - financial arrangements for the monitoring plan.

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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