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Averting shallow-well contamination in Uganda

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DESPITE AN ABUNDANCE of surface water in Uganda (18% of the land area), the predominantly rural (>90%) population relies almost exclusively on groundwater for a potable water supply. This dependence arises from the more widespread occurrence, superior quality and reduced susceptibility to contamination, of groundwater supplies compared to surface-water sources. As a result, provision of safe water to rural communities in Uganda has depended primarily upon the construction of wells and protection of spring discharges.

In Uganda, as with other regions in equatorial Africa featuring extensive, weathered crystalline rock, often referred to as the 'basement complex', groundwater development has targeted two main aquifer units: a deep aquifer of fractured bedrock and a shallow, muddy-sand aquifer comprising detrital bedrock and alluvium. Particular attention has recently been directed at developing the shallow aquifer since the formation is less costly to develop and a recent study (Howard and others, 1994) has found it is more productive than the deeper, bedrock aquifer. However, monitoring of water quality in south-eastern Uganda, a region of intense shallow-well development, shows that within months of installation, shallow groundwaters commonly exhibit levels of coliform bacteria and nitrate exceeding W.H.O. health guidelines.

Human and livestock waste excreted in pit latrines, over land or in open-pit wells, called 'scoop wells', may contain worms, protozoa, bacteria and viruses that, if consumed, can lead to the contraction of hepatitis, typhoid, cholera and a variety of diarrhoeal diseases. Wells and springs harvesting shallow groundwaters are generally protected from these pathogens by a granular soil matrix which both filters bacteria, protozoa and worms due to their relatively large diameter (>0.5μm) in relation to the aquifer material, and adsorbs smaller viruses (0.07μm to 0.7μm) on account of their strong, negative surface charge. Despite this cleansing capacity, the presence of coliform group of bacteria in groundwater indicates that faecal contamination has occurred (Lewis and others, 1980). High nitrate concentrations also indicate contamination from sewage sources since nitrogenous material, which is uncommon to the subsurface mineralogy, forms a significant component of human and animal waste, and is oxidised to nitrate under the aerobic conditions of shallow groundwaters. The risks associated with elevated nitrate levels (>50mg/L) include methaemoglobinaemia in young infants and the development of gastric cancer.

Contamination of the shallow, weathered aquifer from domestic sewage has been observed across equatorial Africa. In Nigeria, large nitrate increases in shallow wells demonstrate strong correlations with denser human settlements and hence, the number of waste facilities (Langenegger, 1981; Malomo and others, 1990). This pattern has similarly been noted in northern Uganda by Howard and others (1994). In The Gambia, Barrell and Rowland (1979) found dramatic increases in faecal coliforms coincident with the onset of monsoonal rainfall and surmised that deposited faecal material was being flushed either through the weathered soil or directly round poorly sealed well shafts. Such contaminant pathways are possible in Uganda where subsurface infiltration (i.e. recharge) has been shown to coincide with monsoonal rainfall (Howard and others, 1994).

One method of reducing well and spring contamination is to ensure that waterpoints and pollutant sources (e.g. pit latrines, scoop wells) are sufficiently separated to minimise the migration of pathogens into a pumping well or discharging spring. This region around a waterpoint is known as a Wellhead Protection Area (WHPA) and may be defined in a variety of ways. In this paper, we present evidence of shallow well contamination from domestic sewage in Mukono District of southeastern Uganda (Figure 1) and, equipped with a recently-gained understanding of the shallow, muddy-sand aquifer (Howard and

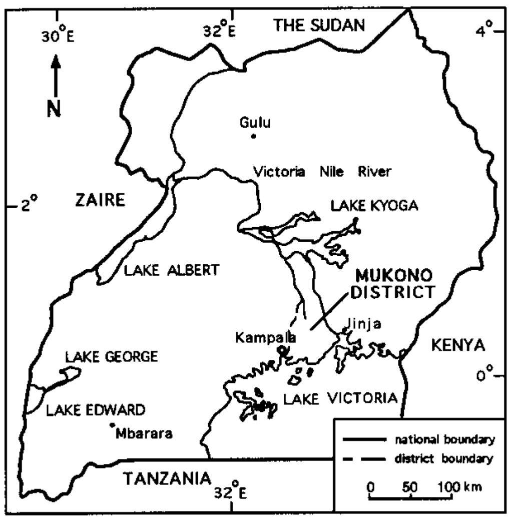

Figure 1. Mukono district in south-eastern Uganda

others, 1994), delineate WHPAs using simulations of groundwater flow with FLOWPATH (Franz and Guiguer, 1994).

Regional hydrogeology

Shallow unconsolidated formations in Mukono District are derived from the prolonged weathering of Precambrian crystalline bedrock of the Granulitic-Gneissic complex, which covers much of central and northern Uganda, and the Buganda-Toro system of mica schists, acid gneisses and quartzites. Quaternary sediments line the Victoria Nile river and Sezibwa swamp as well as the north shore of Lake Victoria (Figure 1). Grain-size analyses of soil, weathered from the granulitic-gneissic complex in northern Uganda, show the shallow aquifer to be composed of a muddy sand. Water well records and geophysical surveys reveal an aquifer thickness of at least 10m (Howard and others, 1994). Analysis of pumping tests conducted at 60 shallow wells in Mukono indicates the aquifer is largely unconfined with an arithmetic mean hydraulic conductivity of 0.2m / day. Well construction commonly occurs near scoop wells and swamps because the presence of a shallow water table in these areas inhibits the formation of duricrusts, which are impenetrable by hand-drilling, and virtually guarantees water will be found. However, with an average depth to water of just 2.6m, the length and time (in some cases as little as 2 weeks) during which the granular medium is able to remove surface wastes before they enter the groundwater system, is limited. Pumping tests achieved an average, steady-state drawdown of 4.5m using a mean pumping rate of 12L / minute, a value which is similar to the capacity of most handpumps. Consequently, steep hydraulic gradients can develop between shallow wells and the sources of pollutants (scoop wells and swamps).

Shallow-well water quality

The biological and chemical quality of water from 10 shallow wells in Mukono District was evaluated at the beginning of the first rainy season in April (1994) and three months later during the short dry season in July. Site selection depended upon the presence of an adjacent scoop well which was also analysed in July, 1994, for its biological and chemical quality. Results of the biological tests are presented in Table 1. Only total coliform counts were considered since false, positive readings for faecal coliforms have been observed in tropical environments using standard methods (Barrel and Rowland, 1979).

All of the scoop wells exhibit severe faecal contamination with total coliform counts well in excess of 100 per 100mL. As such, they clearly constitute a potential source of contamination to adjacent shallow wells. Significantly, at the three sites where the scoop well had either been filled in or dried up, total coliform counts in the shallow wells declined dramatically and in two instances fell to within acceptable levels (L10 count / 100mL; World Health Organisation, 1985). At the remaining seven sites with an operating scoop well, six shallow wells show unacceptably high coliform counts ranging from 12 to 97 per 100mL. At four of these sites, total coliform counts have risen since initial testing in April. With respect to nitrate levels, the average concentration in the seven shallow wells having an adjacent scoop well is considerably higher (11mg / L) than the average amount recorded in sixty shallow wells at the time of their construction (1.0mg / L).

Table 1. Distance between shallow wells and their adjacent scoop well, and total coliform levels recorded in scoop wells (July 1994) and shallow wells (April & July, 1994).

Shallow well #	*Scoop well distance (m)*	*Total coliform scoop well*	*Total coliform April 1994*	*Total coliform July 1994*
AW057	10	600	167	31
AW091	4	>1000	31	17
AW136	20	900	4	58
AW137	10	413	39	61
AW191	filled in	–	41	1
AW193	50	>1200	2	0
AW194	dried up	–	61	0
AW197	35	119	0	103
AW220	dried up	–	>300	53
AW251	100	>1200	0	97

Total coliform: total # of coliforms in a 100ml sample.
Scoop well: adjacent scoop well.

Both the total coliform and nitrate data show deterioration of shallow-well, water quality in the presence of a polluted scoop well. No apparent relationship exists, however, between the magnitude of contamination and the distance separating scoop wells from shallow wells. The possibility that surface waste is being flushed by heavy rains through lateritic soils is unlikely since background nitrate levels in the shallow aquifer, measured at the time of well construction, were low. Contaminant migration down poorly-sealed well casings is also unlikely since this pathway would fail to explain the improvement noted in coliform counts at shallow wells where the scoop well had either filled in or dried up. Although inconclusive, the total coliform and nitrate evidence strongly implies nearby scoop wells are a key threat to shallow-well water quality. Delineation of a safe distance between shallow wells and point sources of faecal contamination such as scoop wells and pit latrines, is necessary in order to ensure the sustainability of this potable water supply.

Delineation of wellhead protection areas (WHPAs)

A wellhead protection area (WHPA) is the region around a well where contaminant sources could pose a threat to drinking water drawn from the well. Determination of WHPAs requires both an understanding of the aquifer's hydrogeological characteristics and the selection of appropriate criteria to delimit WHPAs such as the time for

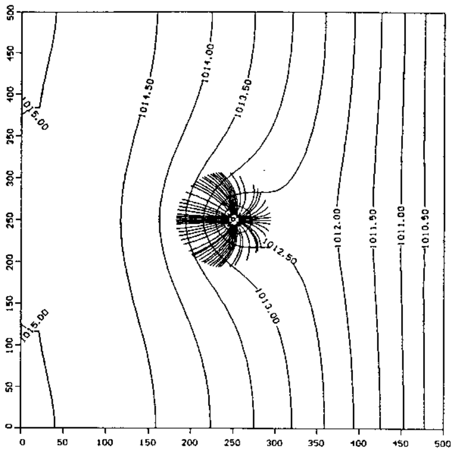

Figure 2. Flowpath simulation of a shallow well pumping under a uniform hydraulic gradient of 0.01. The hydraulic head contour interval is 0.5m.

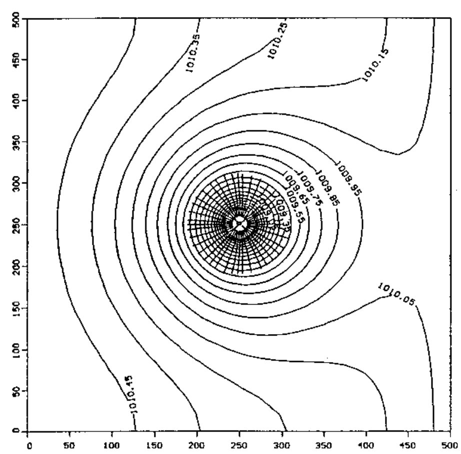

Figure 3. Flowpath simulation of a shallow well pumping under a uniform hydraulic gradient of 0.001. The hydraulic head contour interval is 0.05m.

a contaminant to reach the pumping well or the extent of hydraulic depression caused by the pumping well. In this paper, WHPAs were defined using two-dimensional, groundwater flow models developed with the finite-difference code, FLOWPATH (ver. 5.11) (Franz and Guiguer, 1994). Flow within an area of 500m x 500m was simulated with a well, positioned at its centre, pumping at a rate of 10L / minute for a desirable well lifetime of 10 years. In addition to the hydrogeological parameters stated earlier, an effective porosity of 35% was assumed for the muddy-sand formation. Hydraulic gradients tend to follow the typography of weathered soils within the East African plateau resting between 0.01 and 0.001.

Figure 2 shows equipotential lines (lines of equal hydraulic head) and pathlines of groundwater flow toward a shallow well pumping over a 10-year period. Despite the asymmetry caused by the direction of the hydraulic gradient (0.01 from left to right, prior to pumping) the simulation shows that over a 10-year lifetime, a shallow well draws water from up to 60m away. In two years, groundwater over a 25m radius is pumped. In a uniform flow field with a reduced hydraulic gradient of 0.001 (Figure 3), the pathlines exhibit improved symmetry around the pumping well but extend similarly 60m from the well. Although not presented, a reduction in the pumping rate to 4L / minute decreases the length of pathlines to 40m, over a 10 year period, and to 15m, in 2 years. In all of the above simulations, pathlines reveal the extent of a pumping well's influence over time and so, represent the distance a non-reactive pollutant, like chloride, would travel over that period to reach the well. Nitrate, though susceptible to denitrification processes, also behaves conservatively. Biological pathogens, on the other hand, move more slowly and have a limited life expectancy. Presented pathlines, therefore, serve as generalised conservative estimates of the wellhead protection area.

Conclusions and recommendations

The practice of siting shallow wells in the vicinity of existing scoop wells has been identified as a probable source of faecal contamination to shallow wells in Mukono District of southeastern Uganda. Simulations of groundwater flow in the shallow aquifer indicate that a wellhead protection area of 60m between wells and contaminant sources such as scoop wells, pit latrines and swamps is required to ensure the sustainability of this vital, potable source of water to rural communities. The impact of site variations such as the hydraulic gradient (local slope), as well as the rate and duration of well pumping which are critical for effective planning and surveying of groundwater development activities, have been evaluated. Continued monitoring of shallow groundwater quality is necessary in order to evaluate whether the suggested minimum separation (60m) between wells and contaminant sources, known as a Wellhead Protection Area, is adequate.

The occurrence of swamps and scoop wells coincides with the presence of a near-surface water table. As a result, the institution of WHPAs in Uganda will lead to the construction of shallow wells away from these pollutant sources, in areas where the water table is deeper and the lateritic crust may be impenetrable by hand drilling. In these situations, machine drilling can assist in boring through the crust.

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