A note on irrigation from 'shallow' groundwater in the context of AMGRAF project

AMGRAF Project Report, 2014

Assessing technical feasibility of small-scale groundwater irrigation involves balancing considerations of water-table depth, well yield, technology (power) available for pumping, crop water demand and area irrigated.

(i) Depth to groundwater

Most sources on groundwater in SSA seem to regard 'shallow' groundwater as any aquifer up to 50m or 60m depth. For the purpose of AMGRAF we adopted a working definition of <25m depth. Evidence from the pilot study indicates that typical wells are 10m to 12m deep but water-table drops deeper during the dry season and wells go dry.

Much of the existing small-scale irrigation from groundwater depends on a water-table depth less than 5m (Figure 1) because of power limits on water lifting and also because of available technology. Depths of 50m or 60m cannot be regarded as easily accessible for small-scale irrigation. A working definition of <25m still holds.

(ii) Well yield

Typical well yields are reported as 3.6 - 18 m^3/h for unconsolidated sediments in Ethiopia and 1 -18 m^3/h for representative examples in Upper East region of Ghana.

It will be seen that yields in this range generally do not represent a constraint to human power water lifting but start to become a problem with mechanically powered pumping. Pumping at a rate of 3.6 m^3/h is likely to require above ground storage to allow efficient and convenient irrigation (Figure 2).

Figure 1: Rope and bucket irrigation

Figure 2: Low-head drip irrigation

(iii) Water lifting technology

Currently available options appear to be rope and bucket (human power), treadle pump (human power), chain-and-washer pump (human power), small centrifugal pumps (petrol or diesel power).

Important considerations are (a) power available for lifting water and (b) limit on suction lift.

Human power. Sources suggest (eg. Fraenkel, 1986) that a reasonably fit human can sustain a power output of 75W. The type of water lifting device makes little difference to power requirement but does affect ability to sustain it for long periods. The following flowrates can therefore be achieved assuming a water lifting device with 50% efficiency:-

Head (m)	0.5	1.0	2.5	5.0	10.0
Flow (m^3/h)	27.5	13.8	5.5	2.7	1.3

Animal power. Fraenkel (1986) provides estimates of power capabilities of various draft animals. Assuming again 50% efficiency we can estimate pumping rates as follows:-

Animal	Weight (kg)	Power (W)	Pumping rate (m^3/h) at various heads		
			1.0m	5.0m	10.0m
Mule	350 - 500	300 - 600	54 - 108	10.8 - 21.6	5.4 - 10.8
Donkey	150 - 300	75 - 200	13.8 - 36.8	2.7 - 7.2	1.3 - 3.7
Bullock/ox	500 - 900	300 - 500	54 - 90	10.8 - 18.0	5.4 - 9.0

Petrol/diesel power. Small motorised pumps with rated power output of 0.5hp (375W) or 1hp (750W) are most likely to be appropriate for pumping from shallow wells. Assuming 50% efficiency it can be seen that pumping rates will be in the same range shown above for animal power. However, it should be noted that actual operating efficiency may be lower (perhaps 25%) for commonly available centrifugal pumps because of the nature of the efficiency curve for such pumps.

The issue of limit on suction lift applies to any rotodynamic pumps (centrifugal or axial flow). For such pumps the theoretical limit to suction lift is around 10m but the practical limit is more like 7m where the pump is installed at sea level. Given that many applications will be at altitudes up to 2000m, the limit on suction lift may be as little as 3m. Clearly this is an important consideration if we wish to pump from a well. A pump installed at the surface can be used for only very shallow water-table conditions (say 3-5m depth). It may be possible to modify well design to allow for the pump to be installed on a platform at an intermediate depth, but practical considerations will still limit applications to water-table depth not exceeding 10m and this represents a risk of aquifer pollution.

To avoid the suction lift constraint we have to consider alternative types of pump:

Positive displacement pumps. Handpumps installed on typical water supply wells are positive displacement (piston and valve type) pumps. The Rower pump (Fraenkel, 1986) is a piston pump developed for irrigation use and can deliver around 2.7 m^3/h for a lift of 5-6m, which corresponds to the pumping rate calculated above. The treadle pump is a reciprocating diaphragm pump developed for irrigation use for which quoted delivery rate is again around 3m^3/h for a lift of around 5m. The main difference between various types of hand pump appears to be mainly ergonomic such that the ability to sustain pumping for extended periods may vary but rate of pumping stays much the same. The chain-and-washer type pump may offer somewhat higher pumping rates as quoted efficiency values appear to be a bit higher (perhaps) 75%. Motorised positive displacement pumps exist. The type that is most suitable for borehole use is the progressive cavity type (Mono pump).

Submersible pumps. The mono pump is an example of a 'submersible' pump in which the working element of the pump is below the water table. This requires a long drive-shaft to deliver rotary power from a motor (or hand crank) on the surface to the rotor which is installed below the water-table. The most common type of submersible pump uses an electric motor which is integral with the pump with both being installed below the water-table.

Availability of electrical supply to the well is an obvious constraint on electric submersible pumps but solar power is becoming a feasible and affordable option.

(iv) Crop water demand

Irrigation demand depends on crop type and local environmental conditions, but these do not make a big difference when considering general feasibility. For the range of crops and conditions likely to be encountered in AMGRAF sites, we can anticipate demand at 5-8mm/day. Distance of delivery from the well to the crop will be short, so it is reasonable to assume an irrigation efficiency of 80%.

Under these assumptions, daily water use (m^3/day) can be calculated as shown below.

Irrigation demand (mm/day)	Area irrigated (ha)			
	0.1	0.25	0.5	1.0
5	4.0	10.0	20.0	40.0
6	4.8	12.0	24.0	48.0
7	5.6	14.0	28.0	56.0
8	6.4	16.0	32.0	64.0

Conclusions

1. It is immediately apparent that human powered water lifting cannot irrigate more than 0.1ha for a water-table deeper than about 3m. For a water-table at 10m depth it requires 3 to 4 hours continuous effort to irrigate an area of 0.1ha.
2. Animal power will allow an increase in the area of irrigation to about 0.5ha. However the associated rate of pumping is at the upper end of expected well yield and the system may actually be limited by the aquifer rather than by power for water lifting.
3. Motorised pumps at 0.5hp (375W) deliver a flowrate very similar to what is achievable with animal power and the same considerations therefore apply.
4. Motorised pumps at 1hp (750W) deliver a flowrate that is above the expected yield from shallow aquifers. Continuous pumping from the well will not be possible. It will be desirable to adopt a well design that increase yield (galleries) or provides storage (over-size well).
5. Well yield 3.6 m^3/h is equivalent to continuous pumping at 1 l/s. This is a very low rate for efficient irrigation. Pumping to an above-ground storage tank will offer an improved system.
6. Suction lift is a serious problem for a water-table deeper than 5m. Pumping devices with shaft drive or electric submersible pumps will be required.