(b) Problems met with:

- Inability to deal with the essential technical issues, in particular sticking to the crop calendar and the overlapping of mineral fertilisation as a function of the plant growing cycle;

- Lack of rest for the small farmers in the annual double-cropping;

- Overlapping of work times (irrigation scheme and traditional fields);

- Management of infrastructure, mainly the motorpump and irrigation network.

These different points are at present being dealt with in detail and adequate solutions are at present being recommended. These are to make investments profitable and to encourage take-over by the small farmers.

With a view to this, the project is in the process of putting the emphasis on:

- Training the small farmers and follow-up of the scheme;
- Awareness and extension of modern techniques;
- Improving the system of supplementary pumping for the traditional fields;
- Conservation of, and experimentation with, traditional strains with the intention of determining their potential and of improving cultivation methods.

(c) What has been learnt: In all, the project has:

- Carried out studies of development sites (50 ha);
- Set up infrastructure intended to consolidate the scheme and put the tools for working on the scheme at the disposal of the small farmers;
- Trained and introduced the small farmers to canal and masonry techniques;
- Achieved improved crop practices as much on the scheme as on the traditional fields;
- Diversified crops;
- Practised new techniques to produce seedlings in seedbeds of local strains used in the traditional fields;
- Achieved control and good water management from infrastructure created at the scheme level.

GROUNDWATER DEVELOPMENT FOR SMALL SCALE IRRIGATION IN SUB-SAHARAN AFRICA: TECHNOLOGY FOR SMALL SCALE GROUNDWATER IRRIGATION IN NORTHERN NIGERIA[1]

Richard Carter
Senior Lecturer in Water Supply & Management
Silsoe College, Bedford MK45 4DT, UK

INTRODUCTION

In northern Nigeria dry season vegetable cultivation has been practised for generations in the *fadamas* or seasonally wet bottom lands (Carter et al, 1983). These fadamas range from localised depressions to major river flood plains. Water is lifted from perennial rivers, water holes and wells by the locally constructed counterpoised device known as the *shaduf*.

This is a labour intensive, low capital cost device which permits the irrigation of approximately 0.1 ha (Nwa, 1981). The main crops irrigated by the shaduf are tomatoes, onions and peppers. Even in the more extensive flood plain fadamas this sort of lift irrigation is largely restricted to the banks of perennial water courses and to the margins of natural water holes.

The technical intervention in recent years has been the introduction of simple technology for the construction of shallow boreholes, together with handpumps and motorpumps, as alternatives to the shaduf. This has increased the potential area of vegetable cultivation back across the flood plain, to cover virtually the whole of the fadama, or at least those areas where the water table is no deeper than about 3-4 m below ground surface.

The method of borehole construction used is described in detail by the present author in BSADP (1984). A 50 mm steel pipe is jetted into the fadama soil by pumping water or bentonite mud through it and using this fluid to return displaced soil to the surface. Usually a temporary casing of about 100 mm diameter is driven at the same time as jetting proceeds, so

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[1] **A longer paper on this topic was first presented to the Geological Society of the UK in 1988. Please contact the author if you could like a copy.**

that permanent 75 mm diameter linings can be placed to the required depth. The lower part of the permanent lining is perforated (saw-cut) PVC. Finally the temporary casing is removed and if necessary gravel can be poured around the well screen. This procedure of well jetting can be used to construct irrigation tubewells up to 10-20 m deep in favourable ground conditions (Carter, 1985). Moreover, the technique is cheap (see below), rapid and able to be carried out by relatively unskilled personnel.

More often than not in Nigeria the preferred system of water abstraction from jetted boreholes is by petrol driven centrifugal pump operating by suction lift. Handpumps have been introduced, but the uptake has been less widespread than with motorpumps.

Cost of and returns to irrigation with this system are summarised below:

Table 1: Costs of and Returns to Lift Irrigation by Motorpump in Northern Nigeria (after Chapman in BSADP, 1984)

Costs (N/ha)	
Labour	215
Seeds	199
Equipment (pump and tubewell)	600
Fertiliser	42
Fuel	360
Marketing	192
Total	1608
Receipts (N/ha)	4883
Gross Margin (N/ha)	3275

Note: Average farm holding 0.66 ha (sample size 58).

The gross margin of more than N3000 (then approximately US$4800) which was possible under the new technology at that time, compares favourably with Chapman's figure of N2163 which was obtainable by non-pump users (shaduf irrigators or residual moisture farmers), (BSADP, 1984). However,

it should be noted that the Naira has been devalued by a factor of more than twenty since the date for which these figures apply. Fuel is still cheap, but imported equipment is affected.

At a seminar in Bauchi State in 1984 various encouragements and warnings were made in relation to future groundwater development of this type. Despite the attractiveness of the concept - and uptake of technology by farmers has been very rapid - a number of areas of concern were identified. These included:

(i) The effects of upstream developments (dams) on both traditional and introduced fadama agriculture;

(ii) The lack of data concerning borehole yields, drawdowns and recovery rates in the fadamas;

(iii) A lack of hard information on groundwater recharge, especially in fadamas affected by upstream developments;

(iv) The lack of any legislative control on groundwater abstraction.

Many of these aspects have been studied in the period since 1984, although much work remains to be done. The following sections relate to these concerns and to developments which have occurred in recent years.

1. CONFLICT WITH THE FORMAL SECTOR

Not surprisingly much of the land which is suitable for large scale formal irrigation schemes is that which either is being used or could be developed for small scale irrigation (SSI). So far most of Nigeria's larger irrigation schemes are based on surface water developments (dams in the head reaches of major rivers), and much cultivated and cultivable fadama land has been submerged under reservoirs. Often as much land has been flooded as is commanded by surface water reservoirs in the relatively subdued relief of the north of the country. In addition the combination of dam construction and poor rainfall in recent years has meant that annual floods in the middle and lower reaches of the major rivers have not reached the same magnitudes as formerly. Recharge to the fadamas may have therefore been reduced, with obvious effects on resource availability for SSI.

The reduction in oil revenues in the present decade has reduced the availability of funds for investment in highly capital intensive surface water developments and this has been to the advantage of SSI.

The recent merger once again of the Federal Ministry of Agriculture (which previously looked after small scale development) and the Ministry of Water Resources (which promoted the large formal schemes) at least give the opportunity for a more rational optimisation of combined small and large scale developments.

2. GROUNDWATER EXPLORATION IN THE FADAMAS

The use of electrical, and more recently electromagnetic techniques for groundwater exploration, is well established in the crystalline rock areas of many parts of Africa. In the hard igneous and metamorphic rocks of the Basement Complex groundwater has been located in the weathered zone above fresh rock or in hard rock fractures. With the advent of electromagnetic (EM) profiling the older resistivity profiling (constant separatio traversing) is less used, and now surface geophysical exploration generally consists of a combination of EM profiling and vertical electrical soundings (VES), (see for example, Beeson and Jones, 1988).

It is only recently that the same techniques have been applied in alluvial environments, but a considerable degree of success has been claimed for them there too (Temple-Hazell et al, 1988). The following observations are summarised from recent work of Temple-Hazell's Water Surveys Group in the northern Nigerian fadamas.

Significant aquifers suitable for SSI are to be found in the layered or lenticular sands and gravels of alluvial deposits in the often very extensive (up to 10-15 km wide) major river floodplains. To be compatible with the presently used drilling technology and pumping systems, aquifers with rest water levels no deeper than 4-6 m and in which drilling to 10-15 m depth is adequate, must be located.

The procedures used have included routine EM profiling together with vertical electrical soundings at selected type locations. Computer simulation for VES interpretation has been essential because of the difficulty of manual curve fitting. The greatest difficulty in quantifying thickness of sand and gravel aquifers occurs when they are overlain by highly conductive clay

deposits which may be up to 6 m thick. Even in sequences of sands, overlying clays or silts, in turn overlying highly resistive bedrock, there is significant ambiguity in interpretation of both EM and VES results. However, the major ambiguity is in the predicted thickness of the conductive layer, not the more interesting overlying sand layer.

In all cases geophysical exploration needs to be backed up by drilling, but the advantage of the shallow alluvial environments under consideration is that they can be readily penetrated by low cost techniques such as jetting, auguring or vibro-bailing.

3. GROUNDWATER RESOURCE EVALUATION

The only detailed evaluation of aquifer properties and well characteristics in the Nigerian fadamas appears to be that carried out by the Water Surveys Group (1986)., This work included constant rate and step-drawdown texts on 30 shallow wells in the fadamas of the Gongola, Jama'are and Dingaiya Rivers of Bauchi State.

Sand and gravel aquifers varied in thickness from less than 2 m-16 m (mean 6.6 m, 30 sites). Transmissivity (T) ranged from 100 - 10200. m^2/d (mean 1600 m^2/d). Storage Coefficients (S) were consistently high, ranging between 0.005 and 0.29 (mean 0.11). In some of the constant rate tests evidence of barrier boundaries was found after only 12 h of continuous pumping. Well efficiencies varied from 13-86%.

On the basis of a number of assumptions (mean T and S values, 100% well efficiencies expected abstraction rates of 6.71/s and a typical pumping duration of 6 h) drawdowns were predicted ranging from 0.1-2.0 m. Beyond about 15 m from pumped wells drawdowns were observed to be negligible. In the major fadamas it was estimated that well spacings of 100 m would not cause undue interference, and such spacings would be appropriate in terms of crop water requirements and abstraction rates.

Recharge in the major fadamas studied was observed to be complete in periods varying from one or two days to a maximum of 25 days following the onset of river flow. Water tables rose by about 2 to over 4 m in this period. This observation confirms previous assumptions of complete and rapid recharge, but the effects of major dams (e.g. Tiga, Dadin Kowa and

Challawa) are already being felt in reduced or non-existent flooding and consequent reduced groundwater recharge in other river valleys.

4. DRILLING AND WELL CONSTRUCTION TECHNOLOGY

The main low-cost drilling method used in the northern Nigerian fadamas is still that described in the Introduction - well jetting or washboring. More recently introduced methods include the use of a vibro-bailer (a steel bailer hand-vibrated inside PVC casing, using steel auger extensions as drilling rod) and the placing of drive points. The latter are particularly suitable in thin, otherwise unproductive aquifers - at least when 'Johnson' type (high open area) points are used.

Well screens and casings are normally of 75 mm PVC, the former being hacksaw slotted (usually 1 mm slots, although this is often too large). Slots of 0.5 mm are usually more successful. Open areas can be as little as 4% with hacksaw slots, and still less than 10% with bench slotted PVC. Screen lengths of 5-10 m are needed to ensure entrance velocities are kept within the normally accepted limits.

Well development is generally carried out only by overpumping, whereas surging has been observed to give much improved performance.

Direct connection of pump suction to well casings is reported to give significantly better well performance than the usual practice of lowering the suction pipe well down inside the screen.

The most recent estimates of drilling costs (by jetting or vibro-bailer to complete 9 m deep, 75 mm diameter holes) are US$150-200 per well (Water Surveys Group, 1986). These are based on 320 wells per year for a drilling crew.

It is likely that the efficiency of the well jetting technique can be significantly improved through design modifications. Current research at Silsoe College is concerned with the detailed relationship between nozzle size and angle, water pressure, volume and upward velocity, and hole diameter. These relationships are being investigated under laboratory conditions, and the objective is to optimise drilling performance, especially when well linings are sunk at the same time as drilling. The use of bentonite and other drilling muds is also being investigated.

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