INTEGRATING PRODUCTIVE WATER POINTS INTO RURAL WATER SUPPLY
as a means of coping with drought

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ABSTRACT

Lack of water is preventing many household and community-based activities for millions of people living in dry areas of sub-Saharan Africa. When water becomes available it is put to a wide variety of uses: drinking, washing, food processing, beer brewing, brick making, small-scale irrigation, fruit orchards, livestock feedlots, small-scale dairy etc. Many of these water-related activities have a high economic value. They can play an important role in household income and livelihood strategies, and through diversification can avoid over-reliance on single production activities such as rain-fed cropping of marginal lands. However, the diverse range of production strategies that can be associated with a water point have not formally been promoted. Rural water supply policy has tended to focus on only two social aspects: improved access to domestic supply and improved sanitation. Less attention has been paid to exactly how a community would prefer to use the water to develop their own livelihoods. This is due in part to the difficulties of abstracting sufficient reliable groundwater in dryland areas, and in part to a misunderstanding of why wells and boreholes fail which leads to a general belief that abstraction should be limited to domestic supply to conserve the resource. This paper provides an overview of research that has shed light on why wells and boreholes fail, on the potential of the groundwater resource to support production through improved siting and selection of more appropriate well designs, and on the positive impact that *productive water points* can have on community resource management and livelihood strategies. Productive water points in this context are community-managed water points, designed and implemented as part of rural water supply to provide water surplus to domestic needs which may be used for economically productive purposes. Importantly, they are implemented in a manner that empowers the local people to own the resource and assume responsibility for operation and maintenance. Policy implications of integrating productive water points into national programmes as a means of coping with drought are discussed, drawing on lessons to emerge from Zambia and Zimbabwe.

INTRODUCTION

Over major parts of the earth's surface, the basement of continents outcrop and lie close to the surface in vast shields of igneous and metamorphic rocks. The most common of these "hard rocks" are gneisses and granites. Large parts of this geological domain are located in dryland regions which are among the least developed in the world. From a social and environmental perspective, these areas are among the most fragile parts of the world, with increasing populations having prevailing low per capita income. This is especially true of parts of Brazil, peninsular India, Sri Lanka, Korea, China, the Red Sea region, west Africa from Mauritania and Senegal to Burkina Faso and Cameroon, and extensive parts of central, eastern and southern Africa. The populations concerned are, at least, in the range of 30 million in Latin America, 50 million in Africa and several hundreds of millions in Asia (UNESCO, 1984)

One of the primary constraints to economic and social development in these regions of the world is the difficulty encountered in developing reliable water supplies for the populations. In tropical arid regions, surface water is not available on a permanent basis, while in humid regions it is often contaminated with waterborne pathogens. As a result, groundwater is, generally, the only permanent and safe source of water. However, the search for groundwater and its development in these regions raises a number of problems which until recently were considered almost impossible to solve.

Hard rock aquifers are complex in occurrence and spatially highly variable. From a hydrological point of view, however, they are homogenous in two respects. They have virtually no primary porosity, unlike sandstones and other sedimentary rocks. Instead, they have a secondary porosity due to fracturing and weathering which permits the flow and storage of groundwater. In temperate and higher latitudes they may be classified as having dominant fracture flow, but in tropical and sub-tropical regions, the weathered and often clayey overburden (regolith) provides the main groundwater storage. Boreholes may be completed in the underlying fractured bedrock but yields are low unless interconnected fractures are intercepted that draw on water stored in the regolith; up to 40 per cent fail in drought (Anon., 1992). Traditional dug wells, on the other hand, are completed in the regolith, but again yields are low where poor siting fails to identify sufficient depth of saturated regolith and where the low permeability of the regolith quickly causes localised drawdown of the water table around the well on pumping.

Success rates, generally assessed as a sustained handpump yield of 0.25 l/s (5-10 m^3/day), average some 60-70 per cent in the majority of African countries. There is thus a major cost of substantial numbers of failed wells and boreholes which most developing countries could well wish to avoid. In addition, an average of some 60-70 per cent implies a much lower rate in the more difficult, water-scarce areas where the poorest people often live. In such cases, and following one or more borehole failures, these locations (and communities) are effectively written off by the current approach.

The difficulties of developing basement aquifers has resulted in the use of wells and boreholes as point sources for domestic supply, fitted with a handpump, bucket pump or bucket/windlass. In 1987, the Commonwealth Science Council reported that total abstraction for a rural community with this degree of development will amount to the equivalent of 0.5 mm of recharge, where present evidence suggests that actual recharge is commonly much higher, in the range 50-150 mm. They recommended that at least some of this surplus could be utilised for higher demands, if development methods could be devised which are feasible and economic.

Recent breakthroughs have taken place, both in the methodology and technology for the exploration and development of groundwater in basement aquifers. These have raised considerable hopes for the future of these developing regions. This paper provides a brief overview of groundwater development in hard rock aquifers and the costs and benefits of productive water points that support domestic supply and small-scale irrigation, drawing on lessons to emerge from dryland areas of Zambia and Zimbabwe. The interested reader may refer to Wright (1992), Lovell et al (1999), Moriarty and Lovell (1998) and Waughray et al (1998).

UNDERSTANDING WHY WELLS AND BOREHOLES FAIL

Essentially, wells and boreholes fail due to three factors, acting alone or in combination. These factors, and the counter-measures which can be taken, are listed below:

Cause of water point failure	Counter-measure
1) high natural groundwater recession characteristic of basement aquifers and most severe during extended periods of low rainfall and recharge;	1) improved siting to identify and locate the water point in the greatest depth of saturated weathering;
2) localised drawdown of the water-table around the well or borehole on pumping due to low aquifer permeability	2) improved siting to identify reasonable permeability and selection of more appropriate water point designs suited to low permeability conditions
3) inadequate arrangements for pump maintenance and repair	3) empower the local community to own the resource and assume responsibility for repair

Table 1. The principal causes of water point failure in hard rock aquifers, and the counter-measures that can be taken

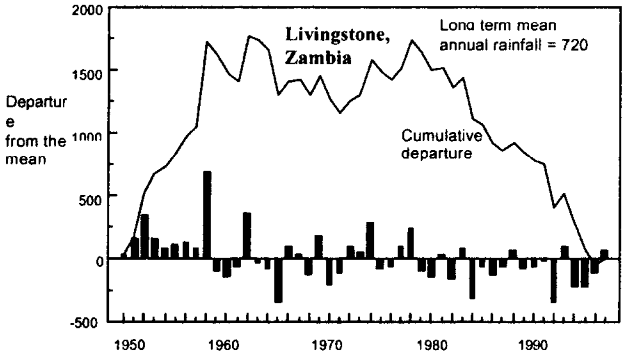

Figure 1. Departure from long-term mean annual rainfall in a dryland area of Zambia

Figure 1 shows the annual and cumulative departure from long term mean annual rainfall for Livingstone in the Southern Province of Zambia. While there is no evidence of an overall decline in rainfall, the trends reflect cycles of above and below average rainfall. When rainfall is low for an extended period (1979-1996), groundwater recharge fails to match natural groundwater recession and groundwater levels fall. This fall in water level leads to many traditional sources drying up, since these tend to be sited convenient to the homestead rather than in optimum depths of saturated weathering, and people are forced to walk long distances to more reliable water points.

	Runoff (mm)	Recharge (mm)	Change in groundwater storage (mm)	Natural recession (mm)	Human abstraction (mm)	Balance to evaporation, change in soil moisture, and other losses (mm)
1994/95 rainfall 738 mm	4	38	-34	72	1	695
1995/96 rainfall 990 mm	93	262	+100	162	1	634
1996/97 rainfall 1140 mm	84	296	+62	234	1	759

Table 2. Annual water balance of Romwe Catchment, Zimbabwe (year 1 July - 30 June) (source: Lovell *et al*, 1998a)

Table 2 shows the annual water balance measured in a small, communally-managed dryland catchment in Zimbabwe in an area of younger undifferentiated gneisses with long term annual rainfall of about 700 mm. Catchment recharge rates up to 300 mm per year have been measured in years of above average rainfall. However, natural groundwater recession, principally through abstraction by deep-rooted vegetation and leakage into the fractured bedrock, directly accounts for up to 230 mm per year of this recharge. Human abstraction for domestic use and small-scale irrigation by the 103 families living in the catchment is trivial, at less than 1 mm per year areal recharge. In this environment, groundwater is not failing because of resource use or human impact through land use change; a ten-fold increase from current use, for example, would still have negligible impact on the natural recession of groundwater. Where conventional wells and boreholes fail it is because they are inadequately sited and or are of inappropriate design to cope with the low rainfall, high natural groundwater recession, high spatial variability and low permeability that characterise hard rock aquifers in dryland areas.

NEW DEVELOPMENT OPTIONS AVAILABLE

Over the last decade, interest in the regolith aquifer has increased with the recognition that this may provide a more sustainable and less costly source of rural water supply than the underlying bedrock fractures previously targeted by boreholes (Howard and Karundu, 1992; Wright, 1992). Recent studies provide three new methodologies for increased abstraction of water from the regolith (Wright *et al*, 1989; Lovell *et al*, 1996):

Screened-regolith boreholes sited by exploratory drilling and drilled to 40 m;
Large-diameter wells sited by exploratory drilling and dug to bedrock;
Large-diameter collector wells sited by exploratory drilling, dug to bedrock, and completed with horizontal boreholes.

Figure 2 illustrates these designs, along with standard boreholes, deep wells, family wells and hand-drilled tubewells. Table 3 shows average sustainable yields recorded in a pumping test comparison. Essentially, the new designs use exploratory drilling to locate maximum depths of saturated weathering and reasonable permeability, and make effective use of the regolith aquifer by screening (rather than casing) and by large diameters (2-3 m) which in low permeability conditions provide sufficient storage for water as the wells fill slowly each night. The horizontal boreholes of the collector well, drilled radially from the base of the large diameter well in several directions to a distance of up to 30 m, are designed specifically to overcome high spatial variability and low permeability where these are particular constraints.

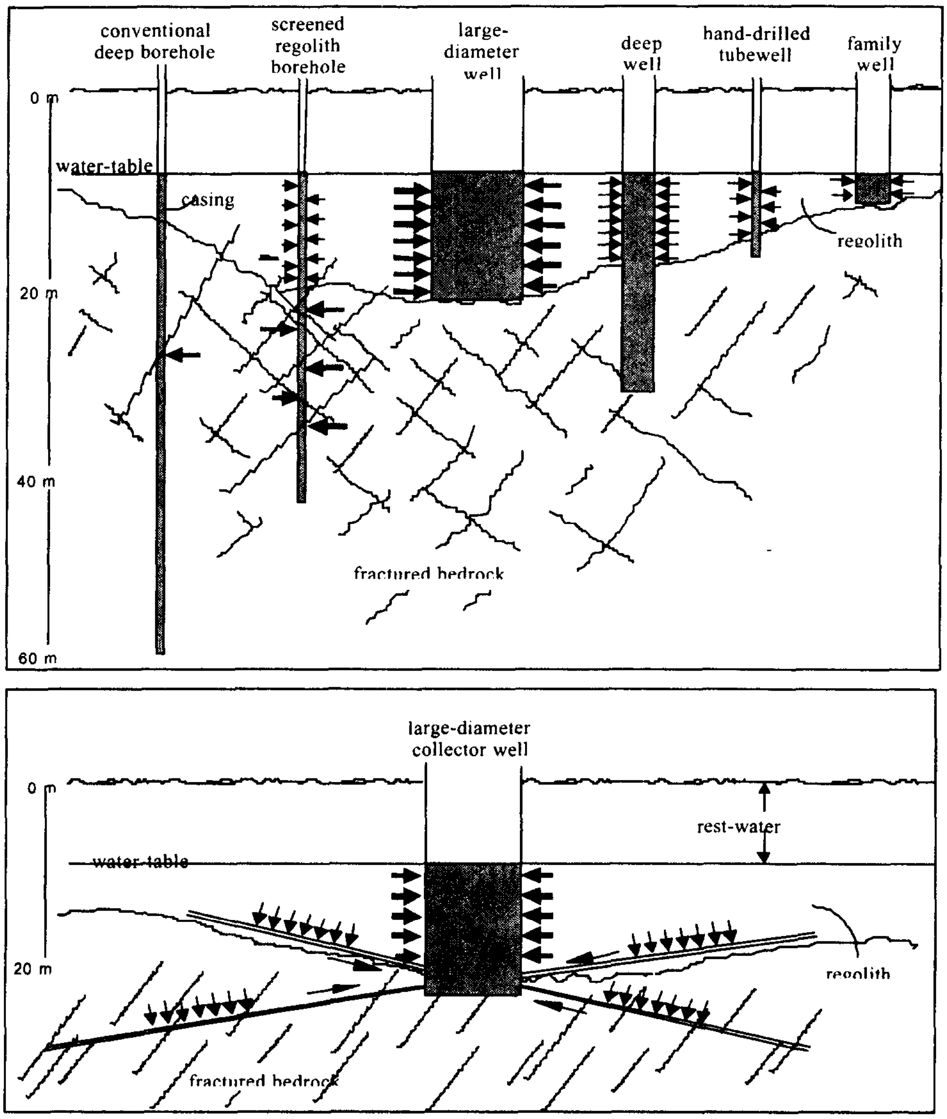

Figure 2. Water point designs used for groundwater abstraction in hard rock aquifers

Well design	Sample size	Av. yield (m^3/day)	Range (m^3/day)	St. Dev. (m^3/day)
Family well or hand-drilled tubewell[1]	110	1.9	0 - 7.4	1.7
Deep well completed into the fractured bedrock[1]	110	7.1	0.1 - 16.5	3.7
Standard borehole, avg. depth 64 m, cased in regolith[2]	149	22.5	0 - 162.0	30.2
Screened-regolith borehole sited by exploratory drilling[3]	5	36.4	26.0 - 45.0	7.1
Large-diameter well sited by exploratory drilling[3]	9	25.1	10.2 - 55.3	15.1
Collector well sited by exploratory drilling[3]	8	29.5	10.8 - 62.5	15.9

1 DFID WaterAid, Bikita District 1993 Emergency Water Supply Programme. No pumping tests. Bucket counts.

2 World Bank, Masvingo Province 1994 Drought Relief Programme. Pumping tests performed. 10 hour pumping day assumed.

3 Pumping tests and modelling to project sustainable yield during drought (source: Lovell et al, 1996)

Table 3. Average yields recorded in a pumping test comparison of water point designs in dryland areas of Zimbabwe

Due to non-rigorous testing of family wells and deep wells in past programmes, and the limited sample size of the new options, it is too early to draw definitive conclusions, but some important lessons are emerging:

Development of the fractured bedrock requires interaction with water stored in the overlying and adjacent regolith. If interconnected fractures are not intercepted, low yields result; about half of all new boreholes drilled are dry or give less than a handpump yield of 5-10 m^3/day. However, where interconnected fissures are intercepted, some very high yields >150 m^3/day may be obtained. Consequently, there are some existing boreholes that are grossly under-utilised because single hand-pump capacity is so far below the safe yield;

Siting to intercept bedrock fractures in basement areas is difficult and success rates are low. Siting new boreholes by shallow exploratory drilling in the regolith to locate greatest depths of saturated weathering appears to help overcome the variability found at depth;

Boreholes in hard rock aquifers would be better if screened in the regolith rather than cased;

Average yields of screened-regolith boreholes, large-diameter wells and collector wells, sited by exploratory drilling and completed in the regolith, although lower than deep borehole yields at some locations, are far more consistent and quite adequate, providing upward of the 15-20 m^3/day of water needed to support domestic use and small-scale irrigation;

The relative importance of the regolith and underlying fractured bedrock aquifers, and the most appropriate development strategies, will vary from region to region depending on the basement geology, tectonic history, climate past and present, and local relief. When planning productive water points it is important, therefore, to consider all potential sources of water, including existing underused resources, and if siting new water points, to select the most appropriate design suited to the local groundwater conditions. Surveys undertaken in drought-prone areas of Zambia and Zimbabwe (Lovell and Lombe, 1998; Lovell and Mtetwa, 1998), where development agencies are presently sinking hundreds of standard boreholes and wells largely irrespective of local groundwater conditions, indicate that nearly half of all existing water points are either under-utilised or of inappropriate design (Box 1).

THE BENEFITS OF PRODUCTIVE GROUNDWATER DEVELOPMENT

The following are some of the benefits recorded at productive water points. For further information, the interested reader may refer to Lovell *et al* (1998b) and Waughray *et al* (1998).

community-based pump maintenance has become a reality - when water is given an economic value through production, it creates both the incentive and the ability for local people to pay for pump repairs

improved reliability of domestic supply - the number of households using the productive water points can rise by as much as 50 per cent as other water sources fail towards the end of each dry season.

increased vegetable consumption and improved nutrition: on average 78 families per scheme grow vegetables, providing an average of 386 kg of produce per household, equivalent to 58 tonnes/ha.

80 per cent of the main decision-makers for the gardens are women;

49 per cent of garden members are amongst the poorest of the poor;

average gross income from selling produce during 1996 was US$28 per member household in an area where 50 per cent of annual incomes were less than US$166.

70 per cent of members use this new source of cash to create revolving funds and savings clubs which are being used to pay school fees and buy inputs for other income generating activities;

over 200 new projects are reported to have started at 7 schemes - the reliability rather than just the size of the garden income flows is said to be critical to the planning and success of these new initiatives.

Box 1. The potential for productive groundwater development: an example

Zambia has experienced severe drought problems in recent years. As a result, food stocks have been depleted, livestock have died or been sold off to buy food, and water resources have generally declined. This decline has been particularly noticeable in the dry Southern Province of the country.

The geology of Southern Province is primarily crystalline basement rocks, basalt, alluvium and sandstone, with aquifers of low groundwater potential relative to many other aquifer types. High spatial variability and low aquifer permeability make siting of productive water points difficult. However, a review of 1000 water point records where sufficient information on rest water level and yield were available, and field visits to a sample of water points in the principal physical settings, found that:

141 existing water points (20%) are high-yielding and under-utilised and could immediately support production if present pump capacity were increased above that of the single hand-pumps fitted;
195 (27%) are low yielding because they are of inappropriate design in shallow aquifers of low permeability; these water points, principally deep boreholes cased in the regolith, should be converted to screened regolith boreholes, large-diameter wells or collector wells and would support production;
151 (21%) are low yielding because of inadequate siting; these water points could potentially benefit from re-siting using a combination of exploratory drilling and geophysical techniques;
229 (32%) of existing water points provide satisfactory domestic supply.

Productive groundwater development has potential to be of considerable benefit both to local people and the local environment if existing water points are more effectively utilised and if new water points are chosen to suit the local aquifer conditions. The figures quoted are estimates but are considered to be of the correct order of magnitude. It is conservatively estimated that 340 productive water points and associated small-scale irrigation schemes of total area 220 ha could immediately be developed to benefit about 85 000 people living in the driest parts of Zambia. Groundwater in Zambia is recognised to be an underused resource, and massive investment is proposed in the national water resources master plan. Over 1000 water points have already been constructed in Southern Province since 1995. Too many are low yielding or dry, not because groundwater is particularly scarce, but because the new water points are inadequately sited and of inappropriate design. Siting and selecting appropriate well designs, and recognising the opportunity for production at the outset rather than returning later to successful water points, would be a more cost effective approach to rural development and bring more immediate benefits to the local people.

HOW MUCH DOES A PRODUCTIVE WATER POINT COST?

The total cost of a given surface or groundwater project is comprised of capital and recurrent costs. Capital costs include the initial costs of exploration, data collection, scheme design, social development, and construction, while recurrent costs include those for energy, labour, operation and maintenance and interest charges. Ideally, all costs should be included and amortised over time to get a clear view of the implications of choosing different technologies. Even then, far reaching conclusions can rarely be drawn in strict economic terms and from a global perspective. For the same type of installation, for example, costs of groundwater development will be lower in areas with favourable hydrogeological conditions and shallow water tables, where materials and skills are available locally, and where greater inputs are available from the user community. But in arid areas underlain with hard rock, with dispersed population settlements and little infrastructure, such costs may be high. Likewise, the decision on whether to use surface or groundwater or a combination of the two has physical, social and economic dimensions. Often surface water is preferred by users: it may be the traditional water source; people are used to its taste; it is free. But in some areas, surface water may be unreliable or contaminated. With the related problems of population growth, overuse and pollution, a switch to either groundwater or conjunctive use for water supply may be necessary and indeed desirable, even though more expensive in some settings. The following cost-benefit analysis of productive water point options undertaken in Zimbabwe, can therefore only provide a means of estimating future trends in other geographical areas. An up-to-date breakdown of costs should be made locally for each technology option before any decisions on the basis of cost differentials are made.

Table 4 shows capital and recurrent costs of four productive water point options, and the relative costs of providing water using standard family wells and boreholes. The capital costs were recorded in 1994 and have been increased to December 1998 US$ prices taking account of local inflation and real devaluation of the Zimbabwe dollar, which increases the cost of imported components. The figures also include 10% to account for the management costs and profits of the entrepreneur. Amortisation periods considered are 20 years for the water points and gardens and 10 years to pump replacement.

The choice of appropriate pump technology at productive water points is key. Pump selection has a significant impact on systems cost, particularly with increasing depth. The options shown match pump capacity to available yield by use of multiple hand or foot pumps or a single motor pump. Zimbabwe 'B' type handpumps and a single mono pump with diesel engine are assumed, the handpumps costing Z$3000 and Z$6000 each at 15 m and 40 m depth, delivering 18 m^3 and 14.4 m^3 per 10 hour pumping day, respectively. The recurrent costs for maintenance at Z$1000 per year are higher than recorded in practice. Fuel costs for the motor pump are estimated at Z$15/litre at 20 litres per day. Although diesel only costs about Z$9/litre at the pumps, this is less than its economic cost. US$1 = Z$37.36.

Gardening benefits are considered in terms of gross margins recorded by communities at nine schemes since 1991 (Lovell *et al*, 1996). Table 4 uses the average return of Z$92 700 recorded in 1998. The lowest figure in 1998 was Z$41 700, the highest Z$155 000. By way of comparison, the average gross margin in 1998 prices at a local small dam project was similar at Z$72 000.

Domestic water costs and benefits are accounted for by the "partial budget analysis". The cashflow of a standard borehole, implemented to provide domestic water only, is subtracted from the cashflow of the productive water point options, which produce domestic water plus garden water. The costs and unquantified benefits of providing domestic water are thus netted out, so that the incremental costs of each option are being compared with the incremental benefits from production. The "partial budget" IRR is always higher than the plain IRR because it includes the economic benefits of providing domestic water i.e. of not having to provide a standard borehole to do this. It is perhaps the more appropriate way to value productive water points since it covers the full range of benefits provided, both productive and domestic. Table 5 shows partial and full IRRs calculated at the different levels of gross margin recorded in 1998.

Internal rates of return: partial IRR (not including costs of providing domestic water) and full IRR	**Gross margins of 41,700 Z$/ha/year**		**Gross margins of 92,700 Z$/ha/year**		**Gross margins of 155,000 Z$/ha/year**	
	partialfull		partialfull		partialfull	
Upgrade underused well or borehole						
a) multiple hand or foot pumps	infinite	34	infinite	72	infinite	112
b) motor pump	infinite	10	infinite	45	infinite	80
New 40 m screened-regolith borehole						
a) multiple hand or foot pumps	54	16	109	36	169	58
b) motor pump	9	no return	55	21	100	42
New 15 m deep large-diameter well						
a) multiple hand or foot pumps	27	5	56	21	87	37
b) motor pump	no return	no return	18	4	42	20
New 15 m deep collector well						
a) multiple hand or foot pumps	19	5	42	20	66	35
b) motor pump	no return	no return	18	6	38	22
Family well	na	-2	na	17	na	32
Average borehole (if made productive)	na	6	na	24	na	40

Table 5. Internal rates of return

POLICY IMPLICATIONS

In general, therefore, this analysis reveals several guiding principles for the development of rural water supply and productive water points in drought prone areas:

groundwater is an under-used resource: a general belief that groundwater should be conserved for domestic use comes from a misunderstanding of why wells and boreholes fail;

rural water supply programmes which implement only standard wells and boreholes, and which focus only on improved access to domestic supply and improved sanitation, are missing an enormous opportunity to bring many more immediate benefits to local people through production;

productive groundwater development is economically viable - a productive water point may carry a higher initial capital cost than a conventional domestic water point, but its benefits accrue over time: not only via lower recurrent costs to the state but also in the range of extended economic and community management benefits to the wider production system;

the vast superiority of upgrading over new source construction, either by increasing pump capacity to match available yield on underused water points, or by converting poor existing water points to more appropriate designs suited to local groundwater conditions;

the important role for new screened regolith boreholes sited by exploratory drilling;

that collector wells will only be the technology of choice in hydrogeological conditions where other options fail, so it is important to adopt an approach to siting and selection that investigates the other options first;

that one has to be careful when considering constructing new small dams to support irrigation because of the high costs per unit of water stored; this is not to say that small dams have no place, on the contrary, a small dam may be all that can be made available in a particular location, but it is important from an economic perspective to consider groundwater options;

the important role for multiple hand or foot pumps fitted to single water points to match and make effective use of the potential yield;

that mechanised pumps become superior to manual pumps only when gardens are producing very high gross margins or are very large; however, communities may prefer mechanisation.

that development agencies now cutting costs by no longer undertaking pumping tests of completed water points are taking a step in the wrong direction: we need to know how much water is being provided for the money being spent in order to promote cost-effective development strategies and plan effective use of the available resource;

the importance of garden gross margins as a decision variable;

that policies of "low-cost" or "traditional methods only" may actually be disadvantageous to present-day communities living in dry areas. Given their increasing exposure to drought and increasing reliance on groundwater to intensify the dryland farming system, a more pragmatic approach to rural water supply will be needed. "Low cost" family wells, for example, are economically viable when they support a kitchen-garden, and are the first and logical choice in areas where they can readily be implemented. However, it requires upward of 13 to match the gross margin returns of a community-based productive water point, to the benefit of fewer individual families and at greater total capital cost. The under-utilised potential of groundwater, the drought resilience of those at risk, and the equitable supply of water, can best be realised by developing a judicious mix of low-cost family wells *and* more expensive but reliable community-owned productive water points.

constraints to the uptake of productive groundwater development in rural water supply, which development agencies may need to address, include: dissemination of the new methodology and technology for exploration and development of groundwater in basement aquifers within rural communities, so that they can demand services other than standard domestic wells and boreholes; dissemination within the public and private sectors so that they can respond to demand and provide the service that people want to buy at a price they will willingly pay; external support to communities through provision of appropriate subsidies and financing mechanisms; reluctance within the water sector to change from, or an inconfessable vested interest in, the standardised approach to construction of new wells and boreholes.

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