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Assessment of the Potential for Non-motorised Irrigation of Small Farms from Streams in Manicaland, Zimbabwe.

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January 1991

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APPENDIX C : PHOTOGRAPHS

A treadle-powered pump (right) and a plastic hydram pump (below) are shown under test at Chitepo Adult Training Centre, Bonda, Manicaland, Zimbabwe in September 1989.

The treadle is of University of Zimbabwe/Loughborough University design and the hydram of Warwick University design.

ASSESSMENT OF THE POTENTIAL FOR THE NON-MOTORISED IRRIGATION OF SMALL FARMS FROM STREAMS IN MANICALAND, ZIMBABWE

by members of
Warwick University Development Technology Unit
in cooperation with the staff of Manicaland Development Association.

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1. INTRODUCTION

The intensification of agriculture in African countries, especially in the traditional sector of their rural economies, is receiving much attention today. This escalation of agricultural activity is seen as an essential means of achieving self- sufficiency in food production (despite rising populations). It is also seen as a way to increasing rural income generation, which would have the valuable effect of removing a prime cause behind over-rapid urbanisation. However, unless considerable care is taken, the intensification of land-use can lead to irreversible degradation of soils. Whilst simply improved farming techniques can do much to increase yields, a substantial improvement in agricultural production usually also entails increasing such inputs as the water, fertiliser and energy used in cultivation.

In Zimbabwe the productivity of most land is water limited. In very few areas can more than one rain-fed crop be harvested each year, and in much of southern and western Zimbabwe even that one crop is often lost in a dry year. Drought relief programmes are then operated. Seasonal malnutrition is also a concern. On large commercial farms, irrigation using water reservoirs or boreholes is widely practised with good results: the hectarage so irrigated has grown rapidly in the last 30 years. On small- holdings in the less fertile land of the Communal Areas, irrigation is, by contrast, quite rare despite being under- estimated in official surveys. The farmers (often women) have little capital, electricity for pumping is not available, the plots are too small or steep for commercial irrigation equipment to be economic and its maintenance can be a problem. For example a petrol-driven pumpset is too powerful, costly and complex for a farmer of 2 hectares and yet is not easily shared. Irrigation often conflicts with farmers' "minimum risk" strategies.

Part of Manicaland is mountainous and has the best rainfall in Zimbabwe. Much of the North and East of the Province is classed as "Agroecological Zone I" on the national map of "Natural Regions and Farming Areas", (a climate advantage which is offset by the steep and rocky nature of much of the land). Many of the streams are perennial. Despite this there is still a long dry season in winter when little rain falls and most cropland lies idle. Besides the three relatively large irrigation schemes operated by DERUDE, a little gravity-fed irrigation is practised in the Communal Areas, but there are very few pumps, long furrows or dams for seasonal water storage. Within the constraints of dry-season stream flows and other demands on surface waters, a substantial expansion of small-holder irrigation seems possible using stream water. Only at a later date will it be necessary to tap underground water, which is generally more costly to access and has special problems (like salination and depletion) in use.

The Manicaland Development Association (MDA) was formed in 1980 to assist rural grassroot communities with their social, economic and agricultural development. MDA has two Training Centres and District Development Committees in seven districts of Manicaland Province. It undertakes agricultural training and extension, it employs domestic technology instructors to improve nutrition and women's welfare and it promotes rural income-generation using appropriate technologies. Its main focus is upon the needs of those living in Communal

Areas. In relation to irrigation, its northern Herbert Chitepo Training Centre (HCTC) at Bonda is well placed for both demonstrations and extension work.

Warwick University has had connections with HCTC since its early days. The University has within its Engineering Department a Development Technology Unit (DTU) that specialises in rural industrialisation and the design of technologies for rural development in Asia and (especially) Africa. One device it has been researching slowly for some years is the water-powered "hydraulic ram pump" pump, seeking to modify traditional designs so that they might be made in small workshops at a cost that would permit their use for irrigation. Early prototypes were build at HCTC in 1986 and 1988. Recently the DTU has obtained British Government funding to accelerate its research into these pumps. The DTU has links with programmes using ram pumps in Zambia and Zaire.

The development of appropriate pumps is only one part of any programme to promote irrigation on smallholdings. There are many possible irrigation techniques (not all using pumps) and many factors affecting the viability of any one method in a particular area. A nine month period of pump testing and improvement at HCTC, involving the placement of a DTU representative there to work with HCTC's Appropriate Technology Section, was started in August 1989. It was decided to attach to this a short study of the relevance of non-motorised smallholder irrigation in Manicaland. The aims of the study carried out between mid-August and mid-September 1989 were:

- to identify major social, economic or geographical constraints on the expansion of irrigation of small plots in Communal Areas
- to develop a better specification for water-lifting devices
- to examine the agricultural options available for the use of extra water.

A further field study was undertaken in December 1990, mainly to clarify the likely area of irrigable land. By this time one of the pumps being tested at Bonda had run continuously for 9 months giving greater confidence in its suitability for irrigation applications.

The Working Paper describes the findings of two studies and records the initial test performance of two pumps (one water- powered, the other human-powered) installed near the Model Farm of CATC. The Paper is necessarily brief and simple, reflecting the brevity and simplicity of the studies. It has been written partly to give a framework to more detailed evaluation in the future, and partly to back up a request for irrigation programme funding that MDA is making.

2. IRRIGATION TECHNOLOGY

2.1 Choice of technology for smallholder irrigation in Manicaland

There are very many ways of supplementing rainfall to increase agricultural yields; irrigation is a well developed art. We are concerned here with a specific group of farmers in a specific area. Namely those living in Communal Areas of the moister parts of Manicaland. Existing irrigation of their dry season gardens is by gravity feed from streams, or is a secondary use of water primarily provided for domestic purposes. In this context it has been already argued that the expansion of irrigation using surface waters should take precedence over the introduction of irrigation using underground water from aquifers.

Of the various methods of applying water to a plot, those that are most efficient in water use - for example sprinkler and drip irrigation - are also those that need the most expensive equipment and highest water pressures. For both reasons they are not suitable primary techniques for the target group. Application by furrow, hosepipe or bucket has therefore been assumed, although in some places particularly permeable soils may require other treatment. Furrow irrigation needs considerable land preparation (of the same sort as erosion limitation on steep plots); a variant is free flooding from a top furrow, which however is inefficient in water use and can cause soil erosion.

Since dry season river flows are only a small fraction of Summer flows, seasonal storage behind small dams is common on large commercial farms. There are few examples of such reservoirs in Communal Lands, and in some parts of Manicaland suitable sites would be hard to find. The cost and degree of cooperation between individual smallholders necessary to construct and safely maintain dams is quite high: dam construction should not normally be a part of any self-managed irrigation schemes for small-scale farmers. There is a number of government-administered smallholder irrigation schemes in Zimbabwe where expensive shared facilities (dams, boreholes) are employed; however these schemes are usually subsidised to a degree that makes them poor models for copying.

Movement of water from source to plot can be by gravity or by pumping. Existing smallholder irrigation uses gravity, but there are many sites where the furrow leading from an abstraction point on a stream to irrigable land would be very costly to create and difficult to maintain. Long furrows, furrows through permeable soils (needing lining) and furrows through rocky terrain (needing blasting) are all likely to be too expensive. Contour furrows need protecting from damage or siltation by cross flows during rains. There is no doubt scope for increasing gravity-fed irrigation in Manicaland, sometimes in conjunction with the creation of very small (even temporary) dams to act both as diversion structures and as overnight water stores. Some of the gravity-fed sites now in use contravene the Stream Bank Protection Regulations, being within 30 metres of a watercourse: enforcement of these regulations is expected to tighten in future.

For a majority of new sites some form of water lifting will be required or will be preferable to the alternative of using a long furrow; it is specifically pumped irrigation that is considered in the rest of this report. In commercial irrigation, engine- driven pumps (the cheapest cost around Z$4000) or electric pumps are invariably used. These are usually uneconomic when irrigating less that 2 hectares. Mains electricity is rarely available at streamsides and photo-voltaic electricity is far too costly. Windpumping also has far too high a capital cost for irrigation pumping in Zimbabawe, even on sites with especially favourable wind regimes.

Three water-lifting techniques meet the requirement for low capital cost, low running cost and simplicity, namely human- powered, animal-powered and water-powered pumping. Animal-driven devices are not known or available in Zimbabwe, although they have been used in Asia for many centuries. They may become of more interest if there is an increase in the use of draught animals in Manicaland, but do not constitute a good option today.

Human-powered irrigation, at least of small plots, is widely practised. Applied to plots of even 0.2 hectares it becomes very arduous. Such a plot requires about 1000 large buckets (10000 litres) of water per day, about 4.5 buckets per minute for 4 hours per day. Even with 3 carriers, such a rate could only be maintained if the distance carried were less than 30 metres and the lift less than say 2.5 metres. Pumping is much preferable to carrying, as it employs energy far more efficiently. Of the many types of "hand" pump, those that make good use of back and leg muscles are superior to those only using arm muscles. It should be possible for a team of two people to raise 10000 litres per day through 5 metres using a human powered pump. In countries where human-powered irrigation is widely used, a lift of about 3 metres is regarded as a limit to viability. Higher lifts are however used in Bangladesh.

The last technique listed above is water-powered pumping. This is only feasible for lifting water from streams in hilly areas as it uses energy extracted from the small fall of a large flow to lift a small flow to a height. There are few water-powered pumps available. In China water turbine-pumpsets are manufactured, and a few other devices exist in particular countries, but the only widely used water-driven pump is the hydraulic ram pump. Even this is unsuitable for irrigation in its usual high-cost, high-lift, low- capacity form; however a variant designed specifically for low- lift irrigation in Africa is becoming available and is described below.

2.2 The hydraulic ram pump

Background.

The automatic hydraulic ram has been used successfully in rural areas for lifting water for nearly two hundred years. The hydraulic ram is a pumping device which utilises energy from the fall of a flow of water to lift a fraction of the supply to a much greater height. Because it has only 2 moving parts and no bearings, it has a reputation for reliability and low maintenance. By its very nature it cannot be used to pump "static" water from ponds or wells: it is restricted to hilly area where stream gradients are relatively steep.

Existing designs

Commercially manufactured ram pumps are usually made from steel castings and have to be imported to Zimbabwe. These are rarely used for irrigation because of:

- the high cost of the rams and large diameter pipe networks needed for irrigation
- the lack of experienced technical back-up to assist system design on site
- the unreliability of spares supply and access to maintenance.

The reasons are particularly true for small farms in remote areas. Secondhand Blakes ram pumps command high prices (Z$4000 upwards) in Zimbabwe today.

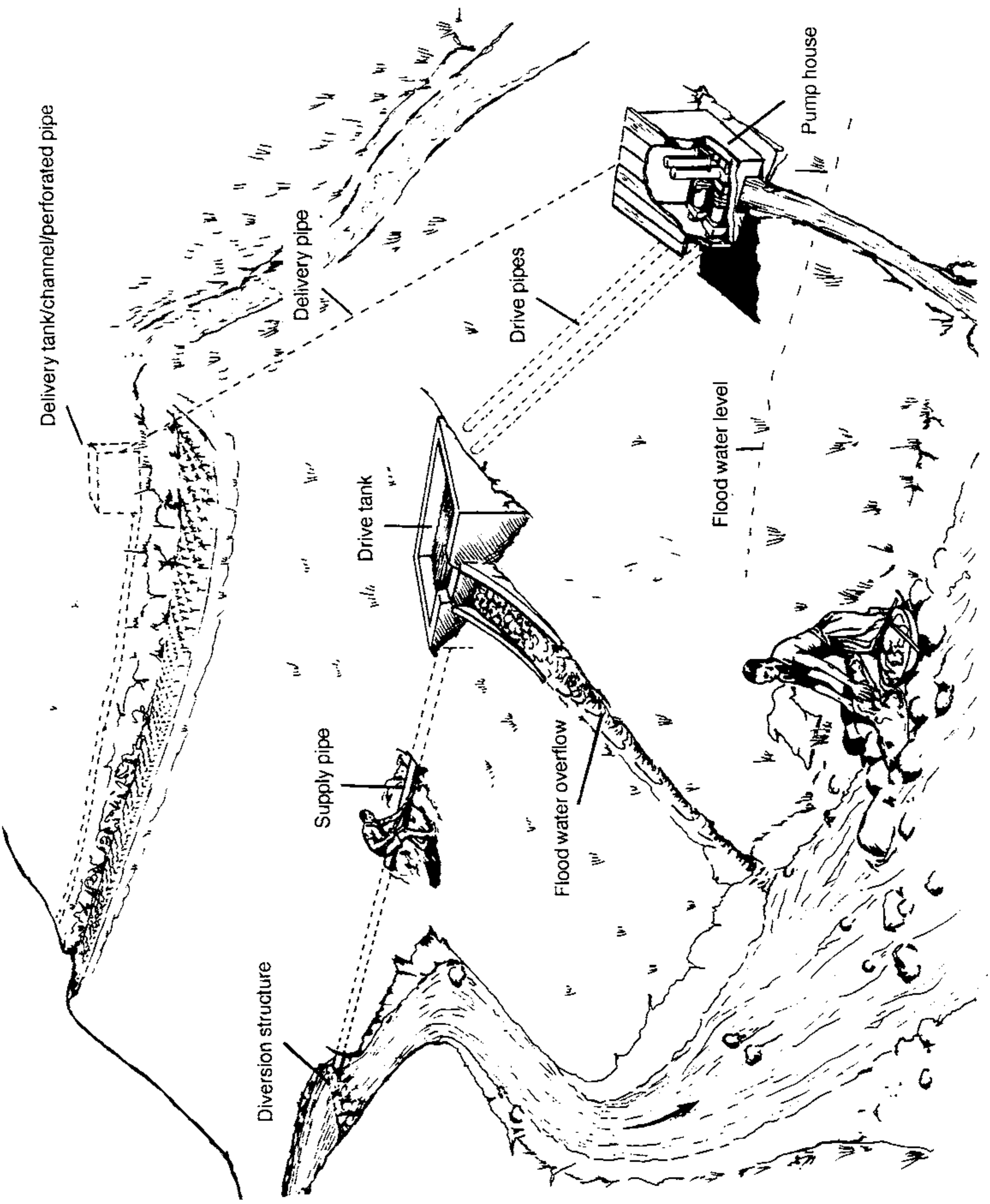
Warwick Design

The low-lift plastic ram pumps developed by the DTU are aimed at small-scale irrigation in Africa. The main design objectives are:

- to produce a pump which can irrigate, reliably, small farms at a height of 12m above a water course
- to make it possible to manufacture within the country of use, preferably in rural areas, using components and tooling techniques widely available
- to create employment in workshops with both manufacture and maintenance.

A hydraulic ram pump system (refer to diagram on the next page.)

The diversion structure channels water flow into a pipe or conduit which follows the contour (with a slight slope) away from the stream to the drive tank. The drive tank is at a point about 2m above the stream. Separate drive pipes bring the flow down the 2m "head" to drive the parallel pumps (between 1 and 4 pumps). A common delivery pipe takes the pumped water up to a delivery tank. The system can deliver about 7% of a stream flow at any single location. Another set of pumps at another location down stream could lift another 7% of the stream flow remaining and so on. This 7% maximum could be increased if the drive head were greater than 2m or the delivery head less than 12m.


Delivery tank/channel/perforated pipe
Delivery pipe
Drive pipes
Pump house
Drive tank
Flood water level
Supply pipe
Flood water overflow
Diversion structure

Performance
The characteristic of a particular (DTU) ram pump was found to be:

Delivery Head (m)	6.2	6.7	9.6	10.0	15.5	16.0	20.3	21.5
Delivery Flow (l/min)	17.0	15.5	12.0	11.3	7.0	6.8	4.6	4.2

The figures in the above table were taken from tests taken with a prototype plastic pump at HCTC, Bonda in September 1989 and are also plotted on the next page. The pump drive head was 1.2m and the delivery pipe had negligible friction. The pump was tuned for maximum delivery, not maximum efficiency, and so the average efficiency was only 23%, which is pretty low. Note how the delivery flow falls as the delivery head is increased. In practice, with the losses in 100m of 25mm delivery pipe, and 30m of conduit, these results would be more representative of a system drive head of 1.5m. From these figures it was predicted that in a standard configuration (2m system drive head and 12m delivery head with a single pump), about 17500 litres per day would be delivered, capable of irrigating about one third of a hectare in the dry season. Reconstruction of the demonstration system at HCTC in 1990 to fit these conditions has confirmed the prediction.

Siting
The siting of a ram pump is a very important part of the system design, affecting both the cost and performance. Some guidelines are:

- choice of a site where the water course falls reasonably rapidly - this will reduce the length of the conduit and make a larger drive head possible
- the flow through each pump should be at least 3 litres/sec (and preferably 6 litres/sec)
- the land for irrigation should not be more than 12m above the pump(s) and as close as possible to the pump system - reducing cost and headloss in the delivery pipe
- there should be some way of protecting the system from flood damage and/or theft - possibly by siting above the high water level, having capabilities for removal, or enclosing in some protective chamber.

Manufacture
Assistance will be required with site selection and installation by trained personnel whose travel would prove costly if they were not locally based. The pumps and spares should be made in- country to ensure the reliability of supply. There are advantages in integrating manufacture with installation because it allows for feedback from the user and a quick, reliable maintenance service. Further, it would be a form of rural employment generation outside agriculture which is greatly needed in Zimbabwe. So, if possible, the pumps should be manufactured locally.

This, however, has implications for the manufacturing techniques used because the numbers of pumps required are unlikely to warrant the purchase of expensive machinery. The system is therefore designed so that it could be manufactured using:

Materials

plastic (PVC) extruded pressure and drain pipe, and standard pipe fittings
standard steel bolts, rods and sheets
concrete

Techniques

use of basic metal and plastic cutting tools
use of a drill and thread cutting dies and taps
use of solvents
basic building skills

Cost

The components to produce one plastic ram pump (including foundations, drive pipe and drive tank) cost about Z$600 and 100m of 25mm diameter delivery pipe costs another Z$400. Allowing a further Z$500 for labour and for the (say 30m) conduit gives an estimated price of Z$1500 for a single pump installation. This includes no provision for storage of the 8 cubic metres of water pumped at night: a concrete tank this size might cost Z$3000 but a pond of this size much less. If several pumps are operated at one site, the cost per pump will be much lower: a 4-ram pump system irrigating 1.2 hectares might cost Z$4000 excluding water storage. Costs are somewhat site specific.

Development status

There are a number of test sites in UK run by the DTU, as well as the one at the Chitepo Training Centre. A workable design is at present being tested, however there is need for improvement and the design features to be improved are:

- durability
- simplicity of manufacture and use of alternatives to components scarce or unavailable in Zimbabwe (for example pressure elbows which have disappeared from the local market)
- overall pump system costs.
- Further areas of development will be:
- increased pump efficiency and performance
- wider sharing of expertise.

2.3 The treadle pump

Background

Broadly speaking, the treadle pump uses foot power through one or two rocking foot bars (or boards) to produce pumping power. The use of feet as the propeller means that the strong leg and back muscles are employed as well as the operator's body weight. Ergonomic research shows that the mechanical advantage over hand pumps can be up to 3 times. Because the treadle pump is human powered, it can of course lift from both static and running water sources.

Harare design

Following research into human-powered pumping by Loughborough University (WEDC) jointly with the University of Zimbabwe (Civil Eng), there have been demonstrations in Harare of both a treadle pump and hand powered "rope and washer" pump. For the reason outlined above the treadle pump is likely to be more appropriate for the large water needs of irrigation.

The Harare design:

- will pump to a maximum of over 15m, but only about 6m is suitable
- has adjustable mechanical advantage - allowing for the different size and strength of the operators and for different lifts
- is made of component easy to fabricate and so replace if needed is manufactured in country.

The pump works by the operator standing on 2 foot bars attached to 2 parallel piston-pumps which are operated by each leg alternately in a walking motion. There is a common suction pipe leading from the water and a common delivery pipe which would be used for direct irrigation, without storage.

Performance

In a test carried out to evaluate the usefulness of a treadle pump, compared to the traditional method of carrying a bucket, we obtained the following results.

	Treadle	**Bucket**
Man A	30.0 litres/min	9.6 litres/min
Man B	30.0 litres/min	12.0 litres/min
Average	30.0 litres/min	10.8 litres/min

This was for a lift of 6m and a carry distance of 40m, working for half hour periods and using 25mm delivery pipe and a 20 litre bucket respectively.

The ratio of efficiencies is 2.8 to 1 in favour of the treadle which (if it was operated for 4 hours in a day) would deliver 7,200 litres. The men involved in the test commented that the treadle was much easier to sustain, and once they were adapted to its motion, they could keep up say 50 minutes pumping in each hour. By contrast, they felt that they needed more frequent rests when carrying buckets. However it must be noted that in contrast to pumping, the effort to carry buckets depends more on distance than on height lifted. Thus the comparative advantage of the pump would decrease with shorter distances carried and increase with longer ones. The distance used in the experiment was only slightly greater than the 30 metres from a stream prohibited from cultivation by law.

Manufacture

The prototype used was manufactured in an informal sector fabrication workshop in Mbare, Harare, where they are in serial production. The sale price for a single pump is about Z$800 to which must be added the cost of a delivery pipe at about Z$4 per metre. No water storage tanks are required. The leather piston cups are bought in, being available on the market.

Development status

The pump is a working product, and a number have been produced in recent months. However it has not experienced extended field use and there is some scope for further improvement. Areas deserving attention include cost reduction, better piston sealing, reduction in the number of welds required for manufacture, addition of an intake filter and simplification of the method of adjusting the machine to users of different physical size (indeed the ergonomics of the pump merit further study and redesign). Research into these issues is under way at Warwick University.

3. AREA IRRIGABLE BY LOW LIFTS FROM STREAMS

Stream water, especially in the dry season, is a scarce resource; existing downstream users will not permit the emptying of streams for irrigation in upstream Communal Areas. An abstraction of 25% of dry-season flows might be an acceptable target for an irrigation programme, after which seasonal storage must be used.

Extensive hydrological records, extending over two or more decades, are available from the Ministry of Water Development which maintains over 20 gauging stations in Manicaland. The rainfall, and the dry season runoff per unit area, vary widely across the Province and even within a given agroeconomic zone. Peak monthly flows vary widely from year to year (although most gauging stations cannot record flows in major floods), but minimum monthly flows are more stable. At one site (Tindini Rodel Township) in 1982-4 for example, peak (February) flows were below 10% of their 10-year average but minimum (September) flows were 40% of their 10-year average. At this location, the September flow exceeded for 9 years out of 10 was about 2.2 l/s for each square km of stream catchment area. By contrast the Mare River near its mouth in Nyanga National Park has a September 90%-exceedance flow of 5.5 l/s per square km of catchment. This latter figure is untypically high, since the Mare River drains Zimbabwe's highest mountain, and its flow is regulated by three dams. We may assume that over the whole of the highland parts of Manicaland (including the Honde Valley) there is about 3 l/s of reliable dry-season flow per square km of catchment.

Using 25% of this 3 l/s yields a flow of 65000 l/day/sq. km, capable of irrigating about 1.3 hectares of land in Winter if applied carefully. On this basis, water availability would appear to limit irrigation to about 1.3% of the land surface. The fraction of the land which is cultivable is not know but is probably around 25%, on which basis some 5% of cultivable land might be irrigated.

In May, rather than September, this fraction might be doubled as mean river flows are about twice those in September.

Table of Mean Monthly Flows over 10 Years at Rodel Township
(Gauging Station DGP 27), expressed as l/s/sq.km of catchment

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow	4.0	4.2	7.2	12.7	20.5	15.8	8.9	7.0	5.8	4.7	3.9	3.4

(Minimum flow recorded in 10 years = 1.2 l/s/sq. km Maximum flow recorded in 10 years = 67 l/s/sq. km)

A more difficult question to answer is "*is 1.3% of the land area topologically suitable for irrigation?*" Suitability requires adequate depth of soil, modest slope (under 8%?) and elevation not more than say 10m above an adjacent stream bed. Subtracting "forbidden" land (within 30m of a stream) from the total, and acknowledging that many of the saddles and outwash aprons surrounding the granite massifs are too high, it seems that in much of highland Manicaland the availability of suitable plots may be as severe a constraint on irrigation as that caused by water shortage.

On a 1:50000 map with 20m contour spacing, a slope of 5% requires contours to be 400m apart, which is 8mm on the map; a slope of under 2% gives contours over 20mm apart. Examinations of map sheets 1832 B3 and B4, 1832 D1 and D2, covering in all about 3000 sq.km of North Manicaland, indicates very little land of under 2% slope. Less than 30% of the land is under cultivation perhaps half of which is slope 5% or more. This scale of map is rather small for such estimates and their confirmation requires more careful work on larger scale maps.

Stream gradients, even in the lower reaches of the Odzi, Pangwe, Honde and Nyadiri Rivers, generally exceed 1% (with valley side 4 to 10 times steeper). Thus conduits (furrows) to attain a height of 10m would be typically 400-800m long. By prudent choice of sites that correspond to rapids, feed pipes to give 2m head to a ram pump would be about 30m long. In general a lift of 5m is required to raise water clear of the immediate stream gorge.

A more detailed study of a particular Communal Area, namely the Honde Valley was made in December 1990. That part of the Honde basin that lies within Zimbabwe has an area of around 500 square kilometres. The valley is extensively cultivated except where slopes exceed 15%: there is little terracing. About half of the Valley is within five kilometres of a metalled road, however the nearest urban market is Mutare, some 70 kilometres from the centre of the area.

The Honde River is, along much of its length, too large and therefore costly to dam, so low-cost irrigation must make use of the water only in tributary streams. Irrigation using manual pumping (and hence no dam) is not generally feasible from this river, given the lift needed from its dry season level to any legally irrigable land. By matching observation (shortly after the first rains of the 1990/91 summer), resident's comments and map studies, it was concluded that only at about four kilometres from its source was any tributary likely to have a usable perennial flow. As a general rule, therefore, water is both available and economically extractable from those parts of streams between 4 kilometres and 15 kilometres from their sources: there is a total length of 40 kilometres of streams satisfying this condition in the Honde Valley.

A head of two metres to drive a ram pump is obtained in part (say 0.6 metres) by constructing a small dam and in part by taking advantage of the natural fall of a stream. Assuming an economic ceiling of 35 metres on drive pipe/feed pipe length, and a local slope at the pump site of three times the average stream slope, gives a minimum "average stream slope" of 1.3% for the installation of water-powered pumps. All the 40 kilometres of stream already shortlisted has a slope exceeding this value.

A stream can also be too steep for water-powered irrigation in that a high slope favours irrigation by gravity via a contour canal. Taking 10 metres as the height above the stream bed to command a useful amount of land that is both above the stream's immediate gorge (typically 5 metres deep) and a legally adequate distance from the water (30 metres), the length of an irrigation canal must exceed 10 metres/streamslope. At stream slopes exceeding 4% (14 kilometres out of the 40 kilometres identified) such a canal would be only 250 metres long and would probably be cheaper to build than an equivalent hydraulic ram pumping station.

There are already a few irrigation canals fed by tributaries on the north side of the Honde River. These tributaries descend a high escarpment, two of them having dramatic waterfalls visible from 10 kilometres away. The one canal investigated (Makanga Valley) carried 1.3 litres per second - enough to irrigate about two hectares. Another canal is reported to be considerably larger. Canal building is not however a common skill and on many otherwise favourable sites hard rock requires blasting or cutting if contour channels are to be created. Once clear of the immediate stream gorge channels can run in softer ground but these suffer from considerable seepage. The present few channels are unlined, but using fibre-cement techniques now being employed for roofing in Manicaland, lining might be economically achievable.

On the south side of the Honde River there is at least one example of irrigation water being piped from a spring. Suitable pipe is now very expensive in Zimbabwe (eg. Z$1600 for 400 metres of 40 mm outside diameter) and such irrigation is only likely to be economic on especially favourable sites where the pipe slope can be maintained at over, say, 8%.

Valley sites in the study area are very variable in terms of stream slope, the depth of the flood gorge and the slope of cultivable land above the flood gorge. About 3% of valley sides are suitable for manual irrigation having shallow gorges and cross slopes under 5%. Another 30% of valley sides appear suitable for ram pump or contour canal irrigation, having gorges not over 5 metres deep and subsequent slopes of 5 to 10%. For both cases each irrigable slope above a gorge is likely to be about 60 metres wide. In total therefore, there are about 4 irrigable hectares per kilometre of suitable river, giving a Honde Valley total of 160 hectares, which is 0.3% of the Valley's area.

River flow records are not available in the Valley, but using the flows derived earlier for adjacent areas, there is ample water for 1.3% of land to be irrigated. This compares with the figure of 0.3% apparently suitable terrain in the Honde Valley. Choosing the lower of these figures and applying it to the total area of Communal Lands in Manicaland lying in Natural Regions I or II (high rainfall) yields a total of about 1,000 hectares of irrigable land, or ten times that number of typical 0.1 hectare gardens. In the short term various factors may reduce this figure by up to 60% and a range of 400 to 1,000 hectares potential may be used. In the long term extensive construction of contour canals could double or treble the irrigable areas.

4. PATTERNS OF IRRIGATED AGRICULTURE

4.1 Dry Versus Wet Season Agriculture

This part of the study attempted to find out how small-scale irrigation usage would effect agricultural practices within the villages visited in N.E. Manicaland. A total of 5 villages were visited all within the Honde Valley region on the 29th August 1989 and 30th August 1989: Hambira, Matingo, Gatsi, Dombomupunga and Nyanguzu. Hambira, Matingo and Gatsi are in the Samaringa Area. Dombomupunga is the Sahumani Area. Nyanguzu is in the Nyasanza Area.

From the information collected it would appear that dry-season irrigation would be the most desirable. This period extends from April to October which is also the winter period. From an irrigation viewpoint this seasonality is quite convenient as it means that irrigation water is required when the evaporative demand from the crops is comparatively low.

There are 3 constraints effecting land which can be irrigated by the hydraulic ram pump or other non-motorised pumps. These are water availability from rivers, the height of land above the river and the economical return that can be obtained from the crops grown on the land. Since the amount of irrigation water made available by each pump is relatively small, enough to irrigate approximately 1/3 ha of land at a height of 10m depending upon the evapotranspiration rate, valuable cash crops would be most appropriate to grow. The Gatsi farmers quoted in 1989 that Z$2000 gross income could be earned per hectare of land if vegetables are grown. The farm manager at CATC observed that at 12 tonnes per ha per crop and prices of 35-40c per kg, for tomatoes or cabbages, 1 hectare could gross Z$4800 per crop of Z$14400 per year. These very different 1989 figures may reflect differences in access to markets. In 1990 a group of women in the Honde Valley (which is warm in winter) estimated the dry season income from a small (20 metres x 20 metres) garden as over Z$5 per day, corresponding to Z$25,000 per hectare per season. These figures are affected by 50% inflation over 16 months. A late 1990 gross additional income of at least Z$16,000 per hectare per year seems obtainable if irrigation is introduced.

Besides the possibility of dry-season cultivation there are three options for wet-season cultivation:

> **Option A** would be to increase cotton or maize crop yields by planting seeds just before the wet season started. Compared to dry season irrigation, under option A it may be possible to irrigate a larger area of land, say 1/2 ha. per pump since seeds for the first 30 days after germination require smaller amounts of water. There is evidence that irrigation in October just before the rains could almost double maize yields, earning Z$400 extra per hectare. Both dry-season irrigation and option A have limits upon the amounts of land which can be irrigated because of low flows in rivers before the rains.
>
> **Option B** is to extend the wet-season cultivation of lower value staple/cash crops. This is possible because in April and May, immediately after the rains, water in the rivers is still fairly plentiful. This option would be more costly since more pumps would need to be installed to meet the water demands, however larger areas can be irrigated than under the other options.

Option C is using the pumps as an insurance policy for the cultivation of staple crops during drought years. Possibly 1 year out of 10 does not receive enough wet-season rainfall for crop survival. Installing costly facilities for use only once or twice a decade is rarely cost effective compared with other forms of drought insurance.

Generally speaking it would not seem viable to install a pump for maize or cotton crop use alone, as assumed in options A, B, and C. This is partly because these crops are of much lower value than vegetables. Also these crops are usually grown some distance away from the rivers at a height greater than 10m. Once a pump was installed however its usage could be extended to options A, B, or C, providing all constraints were met.

4.2 Nutrition and Food Security

Since maize is the only storable crop, in the absence of either irrigation or purchasing power, diet would be restricted to sadza, although there is some tradition of boiling and drying of vegetables. In discussions most families said that they do purchase vegetables to improve their diet during the dry season and their interest in irrigation was in significant part to replace these purchases with their own produce.

In N.E. Manicaland serious drought resulting in loss of crops is fairly rare. It seems unlikely a significant area could be irrigated in a drought year when rivers are particularly low. As discussed earlier the economics of irrigation only used in occasional years are particularly poor and other forms of drought relief in these areas would generally be cheaper. Of course in S.W. Manicaland the situation is quite different and drought relief irrigation systems might be used one year in two.

4.3 Maintaining Fertility

All the farmers visited used artificial fertilisers. This was because on average each household owned only 5 cattle, whilst some owned none. Bags of fertilisers were bought from MDA in 1989 at approximately Z$26 per 50 kg bag however subsequent inflation has been substantial. Normally 5 bags of fertiliser are used for 1 hectare of maize - 3 bags of compound D containing amino- nitrate, potash and potassium nitrate and 2 bags of amino- nitrates. An increase in crop production would mean that a) more nutrients would be taken from the soil and b) the land would not be left fallow for the soil to replenish itself. The common answer to the problem appears to be "add more fertiliser".

There is concern that pumping so much fertiliser into the soil is reducing the organic component of the soil which in turn endangers the soil structure. Environment and Development Organisation in Africa (ENDA) is presently researching methods to increase the organic element. Organic matter other than manures are crop residues, specifically grown compost and soil from elsewhere (eg. anthills). At present the management of dung and crop residues is rather poor. In other parts of Africa where land pressures are higher, composting, zero grazing of animals etc. are used to supplement or replace artificial fertilisers. It would be unwise to rely wholly on artificial fertiliser to provide the extra fertility required when irrigation and multi- cropping is extended. Pesticides are not generally used in Communal Areas because they are both hazardous to health and expensive.

4.4 Soil Erosion

On several of the sites visited, cultivation was being carried out within 30m of the river bed on slopes. Under the "Streambank Protection Regulation" this action is illegal. This Regulation is particularly concerned with reducing siltation in rivers which makes water unavailable to households downstream. Elsewhere, the problems of soil erosion on steep slopes is more a concern of top soil fertility loss which the Regulation does not cover.

From 1989 we were told that the law would be enforced more strictly; the penalties are a Z$25 fine plus the destruction of the crops grown. Farmers are reluctant to give this land up from cultivation, partly because it is an important source of their income, partly because it is so entrenched in their culture and partly because of a lack of realisation of the destruction it causes downstream. However agricultural extension workers have been informing communities of how to prevent unnecessary soil loss. We saw several examples of terracing on the steepest slopes which indicates people's efforts.

Grass leys and furrow ridges were other methods used on more gentle slopes. Grass leys which are grown in contour sections are adequate barriers to soil movement on a slope of 2%. On steeper slopes of 3%, 4% and 5% furrow ridges are needed.

For a 10m lift of water, it seems likely that the land at this height will still be part of the steep valley sides assuming that most river valleys are "V" shaped which is indicated on the survey maps of N.E. Manicaland. If this is the case, soil erosion protection will need to be applied. Agricultural experts are available to mark out the contour lines, but then much person power would be needed to build the furrow ridges. Wild flooding appears to be the type of irrigation known and used in N.E. Manicaland. Water is delivered at several points from a supply channel running along the upper edge of a sloping plot or field and is allowed to move freely down the slope. Its popularity is no doubt due to its simplicity. It is a system involving a minimum amount of land preparation and does not require much labour in operation. However it is dangerous to use it on light soils that are prone to erosion. Also it does not distribute water uniformly, which means extra water is required to ensure that all points receive the necessary amount.

The best way to apply water, especially in situations where the water supply rate is low, for example 20 litres per minute, needs further thought and experimentation. Very careful application of suitable irrigation methods is required on sloping plots.

4.5 Economics and Evidence of User Interest

The foregoing discussion has indicated an extra gross income per hectare, attributable to irrigation of some Z$16000 (in the form of produce sold or in food retained by the cultivator's family). This income has to pay for the irrigation itself, for other inputs and to provide a recompense for the farmers' extra labour. It seems acceptable to assign 50% of this income to payment for the water supplied - Z$8000 per hectare per year. As non- motorised irrigation costs are dominated by the capital costs of initial provision rather than running costs, and as the different components of a pumped irrigation system have a life of between 3 and 15 years, a simple payback period of 3 years has been assumed.

Combining these assumptions yields a ceiling for the capital cost of creating an irrigation system of Z$24000 per hectare. Estimates in section 2.2 and 2.3 suggest that for favourable sites it should be possible to keep well below this ceiling. Overnight storage of irrigation water may create a greater income by using it for fish farming.

According to local farmers there was very strong interest in irrigation being applied on their land. In those places in the Honde Valley, eg. Hambira Village, where gravitational systems were already installed, peoples' initial interest was to expand these. Concerning pumps, they wanted assurances that they would do their job, could be maintained and repaired when they failed and that they would be able to pay back a loan borrowed for their initial purchase over several years. In 1989 the Agricultural Finance Corporation lent money at an interest of 13%. Because this rate was seen as high, farmers were reluctant to take up loans. Interest in irrigation is stronger in 1990 than a year earlier due to most farmers being under greater pressure to generate new income.

5. LEGAL AND SOCIAL IMPLICATIONS

The re-use of domestic water for small gardens is regarded as "Primary" water use. In practice very small-scale irrigation is also unofficially treated as primary water use. Licences are effectively not required for scattered small-scale irrigation of gardens. Different unofficial opinions suggested a ceiling of 1/2 ha. on unlicensed irrigation. In terms of an irrigation programme for Communal Areas, there will come a stage when water abstraction is significant, eg. 10% of flows, at which point licensing probably will be required. Although small farmers no doubt have the political sympathy of the licensing authorities it will be important that they are not thought to use water wastefully.

Income for a typical farmer varies. At present in a good year, she could earn Z$1000 from her farm plus a little more from craft work (eg. crocheting) in Winter. Many of the men work in the towns and can earn Z$2000 per year. However because they require lodgings in the city they may send back only Z$700 per year. The cost of living is going up dramatically, without a corresponding income rise. Because primary education is free, children still go to school, but not all go to secondary school which costs about Z$200 per year per child and is about to rise sharply. Secondary schooling lasts for 4 years from age 14 to 18 and most families can only afford secondary education for 2-4 children.

In all the villages we visited, we spoke only to the women, because they are the farmers. They were all keen to grow another crop during the dry season. The women at Hambira mentioned that there was usually less work to do at this period. This was despite the fact that many had small winter gardens close to their houses, watered by gravity or by bucket. Time is spent collecting firewood and doing limited amounts of gardening. An extra crop would increase their workload but also time would be saved for those who now have to carry buckets of water from the river. They did not see the extra workload as a limiting factor because they would simply employ their family in the fields. A typical family has 7 children, which is beneficial in terms of labour supply. The main ambition of most farmers is to be able to send more of their children to school. Since agriculture is their primary source of income, this indicates the importance of creating more income form irrigated crop production. The women said that they would sell extra crops within the local community since there is no transport to take produce to a bigger market. The local market is best when the schools are open because farmers can sell their produce to the schools and to the school teachers.

For a modest increase in smallholder irrigation neither legalities nor work loads appear to be major constraints. Improvements in marketing, especially in terms of transport, will be required if there is a substantial increase in the production of Winter vegetables.

6. SMALLHOLDER IRRIGATION DEVELOPMENT PROGRAMME

The Manicaland Development Association has for some time wished to respond to the requests of its member groups for help with irrigation. Small-holder irrigation is a specialism in which few are expert, and techniques need careful adaptation to local conditions. If MDA is to mount a major irrigation promotion programme, probably lasting 5 years, that programme is likely to require the following components:

a) The identification and refinement of suitable irrigation water-supply techniques for use in Communal Areas.

b) The identification and refinement of agricultural techniques to make the best use of irrigation water.

c) The identification, in much greater detail than in this study, of user priorities, of physical and legal constraints, of markets for dry-season produce and of favourable specific locations.

d) The creation of an irrigation construction team able to survey, assess, design, procure parts for and oversee the construction of small irrigation schemes by MDA member groups. This may be backed by a workshop making pumps, assistance in marketing and help in obtaining water licences.

e) The establishment of a training and extension programme to disseminate the findings of the research components above, especially with respect to:
- agriculture
- maintenance and operation of irrigation schemes
- (later) construction of new systems.

A good case can be made for incorporating into the irrigation programme a fish-farming component. The two activities can often be profitably combined, sharing some common facilities. Increasing the production of fish protein for sale or local consumption is another of MDA's long term interests.

7. CONCLUSIONS

Within the limitations of a brief study it appears that there is considerable scope for the expansion of dry-season (Winter) irrigation of small plots in the Communal Areas of [illegible] Manicaland using water from small rivers. It is likely that similar conclusions hold for the eastern side of south Manicaland. Using a variety of assumptions it appears that there is enough water to irrigate about 1.5% of the land without requiring seasonal storage of water behind dams. However only 0.3% of land is topologically suitable, which gives a figure of around 1000 hectares in the Communal Areas of Manicaland having good rainfall.

Economically a ceiling of about Z$24000 per hectare has been identified on the capital cost of water provision. Dry-season irrigation appears economically superior to supplementary irrigation just before or after the rains, or to "insurance" irrigation for drought years.

Two suitable pumps have been tested in prototype form. A ram pump system, possible cost Z$1500, lifted enough water in 24 hours to apply 5mm of water to 0.35 hectares of land 10 metres above the headworks, providing a drop of 2 metres was available to drive it. In commercial form, with overnight water storage for each 0.1 hectare garden, multiple-ram pump systems would cost some Z$8000 per hectare. A treadle pump system tested against a lift of 6 metres and a distance carried of 40 metres raised 72000 litres in four hours, enough to irrigate 0.15 hectares: this was 2.8 times greater than raised by the same people in the same time using buckets.

No major legal or social barriers to expanding irrigated gardens were identified and farmers interviewed expressed considerable enthusiasm to expand their incomes in the way. Changes in marketing facilities, especially transport, will probably be needed if dry-season vogetable production is much expanded.

A 5 year programme for MDA to help its member groups expand irrigated agriculture has been outlined.

APPENDIX A:

HYDRAULIC RAM PUMP PERFORMANCE ANALYSIS

In section 2.2 some hydraulic ram pump test results were given. These were obtained in 1989 from the prototype at HCTC. Facilities for the measurement of input water flows (and hence input power) at the test site were very crude, but indicated a drive flow of 6.3 l/s or a little less. Combined with a system drive head of 1.42m, this corresponds to an input power of 88W. On this basis, the results can be restated as follows:

Viable	**Units**								
Lift	m	6.2	6.7	9.6	10.0	15.5	16.0	20.3	21.5
Flow	1/min	17.0	15.5	12.0	11.3	7.0	6.8	4.6	4.2
Flow	1000 l/day	24.5	22.3	17.3	16.3	10.1	9.8	6.6	6.1
Output power	W	17.2	16.9	18.8	18.5	17.8	17.9	15.3	14.7
Efficiency	%	20	19	21	21	20	20	17	17
Pressure swing	%	16	20	13	10	6.5	6	3	3.5

From these figures, the following conclusions may be drawn:

a) The efficiency is very low but fairly constant; the pump adapts to changes in delivery head such that output power is inversely proportional to head.
b) At output heads greater than 20m (corresponding to pressures over 2 bars) performance falls off. In fact the pump durability is unacceptably low at such high pressures.
c) Extrapolating from the test results, a pump lifting water 12m via a delivery pipe having a 1m friction loss should deliver 12500 l/day, or 17500 l/day if the system drive head were increased from 1.42 to 2.0m.
d) The pressure swing figures indicate that for large-flow, low-head applications the pressure vessel is too small.

The low efficiency could be significantly improved, at the cost of a small loss in output, if the pump were retuned to run faster, eg. at 60 rather than 30 strokes per minute.

A separate analysis of individual losses indicated:
the exhaust flow kinetic energy accounts for 21% energy losses
the drive pipe friction " " " " 6% " "
the conduit friction (30m x 110mm pipe) " 15% " "
back-leakage through the delivery valve " 4% " "

This leaves 35% losses to be attributed to impulse-valve leakage, to hydraulic friction in valves and other causes. The percentages above apply to a delivery head of 10m, however only the back-leakage component would be greater at higher heads. Loss reduction requires either better fitting parts or the use of a larger ram pump; it is of importance only where it is desired to abstract a significant proportion (say over 5%) of total stream flow at a single site.

Concerning durability, tests indicate that when delivery heads exceed 15m, the pump is very vulnerable to loss of air in its pressure vessel. Absence of this air results in hammering and the fatigue of components within a few hours. An overpressure relief valve is clearly necessary to protect against this.

Tests also showed that air-control needs further attention. Too much air (gulping) reduces output, whereas failure to draw in any air at all results in the gradual depletion of air in the pressure vessel. Provided the pressure-vessel air is periodically replenished, the pump will operate satisfactorily under water.

Further tests with a modified design in 1990 indicated similar power outputs despite much smaller drive flows. System efficiencies of 40% were obtained, corresponding to pump efficiencies of over 60%.

APPENDIX B:

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